May 10, 2005

Errata Sheet for

Data Quality Assessment Report for the Post-Decontamination Characterization of the Contents of Tank WM-182 at the Idaho Nuclear Technology and Engineering Center Tank Farm Facility, INEEL/EXT-03-00679, revision 1

Errata No. 1:

Based on the associated half-lives for ^{134}Cs (2 years) and ^{103}Ru (39 days), the data reported for ^{134}Cs and ^{103}Ru are false positives. These data should not have been included in the DQA as positive detections. The tables with information for cesium-134 and ruthenium-103 have been modified.

Errata No. 2:

A UCL was generated for Eu-154 and U-234 when only one positive result was reported for these two radionuclides. In later DQAs, it was established that insufficient data are available to perform meaningful statistics in similar situations.

As a result, the following changes are noted:

Table 12. Radionuclides analyzed for in the tank residuals of WM-182.

Detected Analytes		
americium-241	iodine-129	technetium-99
antimony-125	neptunium-237	total strontium
carbon-14	plutonium-238	tritium
cesium-137	plutonium-239	uranium-234[b]
europium-154[b]	plutonium-241	
Undetected Analytes		
cerium-144	manganese-54	silver-108m
cesium-134[a]	niobium-94	silver-110m
curium-242	niobium-95	uranium-235
curium-244	nickel-63	uranium-236
cobalt-58	radium-226	uranium-238
cobalt-60	ruthenium-103[a]	zinc-65
europium-152	ruthenium-106	zirconium-95
europium-155	silver-108m	

a. Reported results are considered to be false positives based on the corresponding half-life and the age of the waste (^{134}Cs half life is 2 years, ^{103}Ru half life is 39 days).
b. Only one positive result was reported for this radionuclide; therefore, insufficient data are available to perform meaningful statistics.

In section 3.1.5, insert text in second paragraph to disclose the reported results for Eu-154 (6.4 E+04 pCi/L) and U-234 (6.18E+02 pCi.L).

In Table 13, the summary statistics shown for cesium-134 and ruthenium-103 have been deleted. The summary statistics for Eu-154 and U-234 have been deleted.

In Table 14, the five number summaries shown for cesium-134 and ruthenium-103 have been deleted. Eu-154 and U-234 have been deleted.

Section 5.5, the last paragraph discussing transformation of U-234 has been deleted.

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In Table 19, the results of the Shapiro-Wilk test for cesium-134 and ruthenium-103 have been deleted. Eu-154 and U-234 (including ln transformation of U-234) have been deleted.

In Table 22, cesium-134 and ruthenium-103 have been deleted from the summary of post-decontamination activities of radionuclides in the rinsate of Tank WM-182. Eu-254 and U-234 have been deleted.

Appendix A, radionuclides, the box plots and normal-quantile plots for cesium-134 (Figure 5 and Figure 6) and ruthenium-103 (Figure 23 and Figure 24) have been deleted. Likewise, the figures for Eu-154 (Figure 9 and Figure 10), U-234 (Figure 33 and Figure 34) and the transformation of U-234 (Figure 35 and Figure 36) have been deleted.

These isotopes have also been removed from the grouped box plot (previously numbered Figure 37, renumbered as Figure 27).

These numbers correspond to the numbers on the grouped box plot.

Number	Radionuclide
1	americium-241
2	carbon-14
3	cesium-137
5	tritium
6	iodine-129
7	neptunium-237
8	plutonium-238
9	plutonium-239
10	plutonium-241
11	antimony-125
12	technetium-99
13	technetium-99 ICP-MS
14	total strontium

Figure 33. Grouped box plots of radionuclide data. Data have been standardized so that distributions are directly comparable.

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Errata No. 2

Because only one positive detection was reported for Eu-154 and U-234, a UCL should not have been generated for these radionuclides.

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Portage Environmental, Inc.
Idaho Falls, Idaho 83402

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for the
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EXECUTIVE SUMMARY

This data quality assessment report documents the assessment of the data collected during the cleaning of the WM-182 liquid waste tank at the Idaho National Engineering and Environmental Laboratory Idaho Nuclear Technology and Engineering Center Tank Farm Facility. This cleaning activity was performed as part of the Resource Conservation and Recovery Act clean closure and Department of Energy high-level waste tank closure activities underway at the Idaho Nuclear Technology and Engineering Center Tank Farm Facility. Tank WM-182 was the first tank cleaned during Tank Farm Facility closure operations. The data assessed in this report were generated from the sample analysis of residual tank liquids remaining after decontamination. Data from the sample analysis of residual solids or the liquids from the tank vault sumps or diversion valve boxes are not analyzed in this document but will be addressed in a subsequent report. The residual tank liquids data were assessed to determine if the concentrations of Resource Conservation and Recovery Act regulated constituents were reduced to levels below the action levels specified for clean closure in the document *Idaho Hazardous Waste Management Act/Resource Conservation and Recovery Act Closure Plan for Idaho Nuclear Technology and Engineering Center Tanks WM-182 and WM-183* (DOE-ID 2003a).

For the Department of Energy high-level waste tank closure, the radionuclide data were compared to the values that were modeled in the performance assessment to be present in liquids remaining in the tanks after decontamination. These modeled levels are not action levels. Rather, they are an indication of whether the estimates of radionuclide concentrations of the performance assessment are reasonable following completion of decontamination activities at any given tank. The data quality assessment shows that it can be confidently stated that the activities of all radionuclides are less than the modeled values with the exception of antimony-125. Antimony-125 is not a significant contributor to radiation dose as described in the performance assessment. The dose contribution by antimony-125 is insignificant at the concentrations detected in WM-182 liquid samples.

The data collected from sampling the post-decontamination, residual, liquid contents of Tank WM-182 were assessed against the criteria for data quality specified in the *Sampling and Analysis Plan for the Post-Decontamination Characterization of the WM-182 and WM-183 Tank Residuals* (INEEL 2002). The specifications for data quality require the data to support decisions with a specified level of confidence that the decisions are accurate. The analysis presented in this report show that the decision-makers can determine that none of the action levels for Resource Conservation and Recovery Act constituents have been exceeded. The decisions associated with no action levels being exceeded can be made with a highly defensible degree of confidence. Additionally a high degree of confidence can be attributed to the hypothesis that the radionuclide concentrations and resulting radiation dose is less than modeled in the performance assessment.

CONTENTS

TABLES

ACRONYMS

CFR	Code of Federal Regulations
CV	coefficient of variation
DQA	data quality assessment
DQO	data quality objective
DOE	Department of Energy
EPA	Environmental Protection Agency
HLW	high-level waste
HWMA	Hazardous Waste Management Act
ICP-MS	inductively coupled plasma-mass spectrometry
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
IQR	inter-quartile range
LCL	lower confidence limit
PA	performance assessment
RCRA	Resource Conservation and Recovery Act
SAP	sampling and analysis plan
TCLP	toxicity characteristic leaching procedure
TFF	Tank Farm Facility
UCL	upper confidence limit

Data Quality Assessment Report for the Post-Decontamination Characterization of the Contents of Tank WM-182 at the Idaho Nuclear Technology and Engineering Center Tank Farm Facility

1. INTRODUCTION

The purpose of data quality assessment (DQA) is to provide a scientific and statistical evaluation of data to determine if the collected data are of the right type, quality, and quantity to support their intended use. The DQA process is designed around the key idea that data quality, as a concept, is only meaningful when it directly relates to the intended use of the data (Environmental Protection Agency [EPA] 2000). Two primary questions can be answered using the DQA process:

1. Does the quality of the data permit decisions to be made with the desired degree of confidence?

2. How well can the sampling design be expected to perform over a wide range of possible outcomes? That is, can the sampling design strategy be expected to perform well in a similar study with the same degree of confidence even if the actual measurements are different than those obtained in the present study?

The first question addresses the immediate needs of the study. If it is concluded that the data are of sufficient quality, then the decision-maker can proceed knowing that a decision can be made using unambiguous data with the confidence specified as desirable during data collection planning. However, if the data do not provide sufficiently strong evidence to support one decision over another, then appropriate data analysis can alert the decision-maker to the degree of ambiguity in the data. If this is the case, an informed decision can be made about how to proceed. For example, based on the data obtained, more data may be collected or the decision-maker may proceed with one decision or another knowing there is a greater than desirable uncertainty in the decision.

The second question addresses the potential future needs of the study. It can be determined how well the sampling design may perform at a different location given that different environmental conditions and outcomes may exist. Since environmental conditions vary from location to location, it is important to examine the sampling design over a large range of possible settings to ensure that the design will be adequate for use in other scenarios.

The data life cycle consists of three steps:

1. Planning

2. Implementation

3. Assessment.

The planning phase consists of documenting the data needs and plans for data collection using the data quality objective (DQO) process. The DQOs define the qualitative and quantitative criteria for specifying the sampling procedure and establish the desired level of confidence for decision-making. The DQOs for this project are documented in the sampling and analysis plan (SAP) associated with this decontamination project (INEEL 2002). The implementation phase consists of collecting the necessary data according to the SAP. Data assessment consists of both data validation, to make sure that all analysis protocols were followed, and the use of the validated data set to determine if the data quality is satisfactory for making the decisions specified in the SAP.

The steps of the DQA process are:

1. Review the DQOs and Sampling Design

2. Conduct a preliminary data review

3. Select a statistical test

4. Verify the assumptions of the selected test

5. Draw conclusions from the data.

These steps are discussed in the following sections.

2. REVIEW OF THE DATA QUALITY OBJECTIVES

The DQOs specify the problem being addressed and the approach that will be taken to address that problem. The DQOs consist of a problem statement, a decision statement, defining the decision inputs, defining study boundaries, developing a decision rule, establishing decision error limits, and optimization of the design.

1. Problem Statement: There is a need to demonstrate that tank decontamination activities have resulted in closure performance objectives being met.

2. Decision Statement: Determine if decontamination of the Tank Farm Facility (TFF) tank systems has resulted in concentrations of constituents or properties (i.e., pH) of concern in the residuals remaining in the TFF system components being below closure performance standards; if not, then the Hazardous Waste Management Act (HWMA)/Resource Conservation and Recovery Act (RCRA) landfill standards and/or alternate Department of Energy (DOE) requirements for closure must be met.

3. Decision Inputs: Concentrations of hazardous constituents and radionuclides present in tanks after decontamination.

4. Study Boundaries:

   a. Spatial Boundaries: Residual decontamination fluids remaining in the tanks following decontamination. The data assessed in this report were generated from the sample analysis of residual tank liquids remaining after decontamination. No data from the sample analysis of residual solids or the liquid from ancillary equipment (the tank vault sumps, diversion valve boxes, cooling coils, and waste transfer lines) are analyzed in this report. Data assessment of sample analysis of ancillary equipment will be addressed in a subsequent report.

   b. Temporal Boundaries: Time from the onset of decontamination to completion of decontamination. This can vary from tank to tank. Decisions made concerning achievement of closure performance standards will apply for a minimum of 100 years of DOE institutional control until the tanks are removed and disposed of (if ever).

   c. Scale of Decision-Making: The assumptions made in developing the performance assessment (PA) (DOE-ID 2003b) will specify the scale of decision-making.

   d. Practical Constraints: It is not possible to obtain samples from all areas of the tank due to restricted access points and sampling methods.

5. Decision Rule: The parameter of interest is the mean concentration of the constituents of concern within the study boundaries. The decision rules are:

   a. *If* the true mean (as estimated by the 95% upper confidence limit [UCL] of the sample mean) concentration of any applicable hazardous waste constituent detected from the tank is greater than or equal to the maximum concentration of contaminants for the toxicity characteristic listed in 40 Code of Federal Regulations (CFR) 261.24 (2002), or *If* the true mean pH (as estimated by the 5% lower confidence limit of the sample mean for acid pH and the 95% UCL of the sample mean for basic pH) of TFF residuals collected from the individual tank or vault sump exhibit the characteristic of corrosivity, *then* either additional decontamination steps will be undertaken or closure to HWMA/RCRA landfill standards will be considered.

b. *If* the true mean (as estimated by the 95% UCL of the sample mean) concentration of any hazardous constituent detected in total constituent analyses of the TFF residuals collected from statistically similar populations (i.e., sample locations) is greater than or equal to the action level specified in the closure plan, *then* additional decontamination steps may be undertaken. Closure to HWMA/RCRA landfill standards will be considered at final closure of the TFF.

6. Decision Error Limits: The outputs for the decision error limits are the null and alternative hypotheses and a quantification of the allowable error rates. The null hypothesis is "The concentration of hazardous or radioactive constituents in TFF residuals following decontamination exceed action levels." Conversely, the alternative hypothesis is "The concentration of hazardous or radioactive constituents in TFF residuals following decontamination are less than action levels." The lower boundary of the gray region (Δ) is set as 80% of the action level for all constituents of concern. The upper boundary of the gray region is always the constituent-specific action level. For pH, the gray region is bounded on one side by 2.0 and 12.0 (the action levels) and on the other side by 2.1 and 12.4 respectively. It was also determined the chance of a false positive decision error (α) will be set at 5% and the chance of a false negative decision error (β) will also be set at 5%.

7. Design Optimization: It was determined that a simple random sampling method would be used to obtain samples. The standard deviation (σ) was estimated to be 10% of the action level. The validity of this assumption will be assessed in this DQA analysis. Given the chosen α, β, and Δ in conjunction with the estimated value for σ, a sample size (n) of 5 was selected using Equation (1):

$$n = \frac{\left(z_{1-\alpha} + z_{1-\beta}\right)^2 \sigma^2}{\Delta^2} + \frac{1}{2} z_{1-\alpha}^2 \tag{1}$$

where

n	=	the appropriate number of samples to collect to satisfy the DQOs
α	=	false positive rate (5% or 0.05)
β	=	false negative rate (5% or 0.05)
σ	=	estimated standard deviation of the population
Δ	=	minimum detectable difference (the difference between the action level and the value at which the decision-maker wants to specify a false negative decision error rate, in this case the Δ is 20% of the constituent-specific action level)
z_x	=	the xth quantile of the standard normal distribution.

Equation (2) shows the solution of this formula for the Tank WM-182 sampling and analysis activity:

$$n = \frac{\left(1.645 + 1.645\right)^2 (10)^2}{(20)^2} + \frac{1}{2}(1.645)^2 = 4.06 \tag{2}$$

Based on the results of Equation (2), five samples of the residual decontamination fluids remaining in the tank were collected for the applicable analyses.

3. PRELIMINARY DATA REVIEW

The purpose of the preliminary data review is to examine the data using graphical methods and numerical summaries to gain familiarity with the data and achieve an understanding of the "structure" of the data. A preliminary data review should be performed whenever data are used regardless of what the data are to be used for. This type of examination allows for identification of appropriate approaches for further analysis and limitations of the data. There are two main approaches to a preliminary data review: (1) calculation of basic statistical quantities (or summary statistics) and (2) graphical representations of the data. Graphical representation of Tank WM-182 data is provided in Appendix A of this report. Thus, this section will discuss the calculated summary statistics and the graphical review of the data will be discussed in the next section when distributions of the data are assessed.

The summary statistics that were calculated for the detected constituents were measures of center (mean and median) and measures of spread (standard deviation, inter-quartile range, and range). One measure that is of primary interest is the center of the data. The average ($\bar{x}$), or the mean, is the most commonly used measure of the central tendency of the data. However, it can be heavily influence by outliers and by non-symmetric data. The mean is calculated using Equation (3):

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{3}$$

where

n = the number of observations

x_i = the i^{th} observation.

The median is the preferred measure of the center of the data if outliers are present in the data or if the data are skewed. The median is the observation such that 50% of the data lie below the median and 50% of the data lie above the median. If the data are symmetric, the mean and the median will be equal to each other.

Another quantity of interest is the spread of the data. The standard deviation (s) is the most commonly used measure of spread. One reason for this is that it is fairly easy to interpret and is used in many other statistical methods. Since it is calculated using the average, it is also sensitive to outliers and to data that are not symmetric. The standard deviation is calculated using Equation (4):

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \tag{4}$$

where

n = the number of observations

x_i = the i^{th} observation

$\bar{x}$ = the mean of the observations.

The coefficient of variation (CV) was also calculated for each detected analyte. The coefficient of variation is a relative measure of variation. That is, it is a measure of the standard deviation relative to the mean. It is, expressed as a percentage. This measure provides a way to more directly compare the standard deviations of two different data sets that may otherwise not be directly comparable. However, it is important to note that since because the data may be very close to zero or very far away from zero, and the spread may be independent from the distance of the mean from zero. Therefore, no cut and dry firm guidelines have been established for interpreting the CV. The formula for calculating the CV is:

$$CV = \frac{s}{\overline{X}} \times 100\% \tag{5}$$

The inter-quartile range (IQR) is a measure of spread that is not influenced by outliers. It is calculated by subtracting the first quartile from the third quartile. The first quartile is the 25^{th} percentile of the data and the third quartile is the 75^{th} percentile of the data. The IQR is a preferred measure of spread if there are extreme outliers in the data. Otherwise the standard deviation is the preferred measure of spread.

Another measure of spread is the range of the data. The range is calculated by subtracting the smallest value in the data from the largest value. It can be a valuable piece of information in characterizing the spread of the data, but can be deceptively large if the data contain any outliers. Therefore, the data should always be examined for outliers when the range is used as a summary statistic.

The five-number summary was calculated for each of the detected organic, inorganic, and radionuclide analytes along with pH. The five-number summary is a presentation of the minimum value, the first quartile, the median, the third quartile, and the maximum value of the data. This summary provides non-parametric information about the general spread and pattern of the data.

It is often difficult to read a table of numerical summary statistics and identify the degree of symmetry or normality of the data. Because of this, the graphical representations found in the appendices are to aid the data user in assessing the symmetry and normality of the data collected. Graphical representations of the data include box plots and normal-quantile plots. Box plots are a way of graphically viewing the five-number summary. Each of the five horizontal lines in the plot represents one of the numbers from the five-number summary. This type of plot allows for a quick and comprehensive analysis of the symmetry of the data. It can be easily determined if the data are symmetric, right-skewed, or left--skewed. Right-skewed data have a lengthened tail on the higher values of the distribution. This tail pulls the mean toward it causing the mean to be high relative to the center of the data. This makes it more likely that a tank will be declared insufficiently decontaminated when, in fact, it is sufficiently clean. Left-skewed data have a lengthened tail on the lower values of the distribution. This tail pulls the mean toward it causing the mean to be lower than the center of the data. Left-skewed data will cause the UCL to be low-biased, making it more likely to show the tank is clean when, in fact, the concentration of that analyte exceeds the action level. The normal-quantile plot is a plot that is used to assess the normality of the data. If the data follow a normal distribution then the points on the graph will lie along a straight line. Any deviations from a straight line are indicative of deviations from normality. If the tails bend away from the line at both of the ends of the line, then the data are asymmetric. If the data veer away from the line at only one end, then the tails of the distribution are either too heavy or too light to assume a normal distribution. It is important to note that no real world data set is perfectly normal so a certain amount of deviation from the line is to be expected, even in data that are sufficiently normal.

Samples retrieved from Tank WM-182 were analyzed for various organic and inorganic constituents as well as various radionuclides. The following sections will provide an overall analysis of the data produced from measurements of constituent concentrations in the samples of the post-decontamination tank contents collected. Each type of analyte (organic constituents, metals, anions and radionuclides) will be discussed separately. Constituents that were not detected will be identified and then detected analytes will be examined statistically.

3.1.1 Organic Constituents

Most of the organic constituents that were analyzed for were not detected in the post-decontamination tank contents. Table 1 presents a list of organic constituents that were measured in the tank residuals and identifies whether or not each measured analyte was detected. Benzaldehyde was detected in one observation with a value of 1.8 μg/L. Thus, it is not possible to perform statistical analysis on this analyte and it will not be present in any of the other organic analysis tables or graphics. Table 2 presents measures of central tendency and spread for organic analytes. Table 3 provides the five-number summary for each of the detected analytes. The associated box-plots are in Appendix A.

The organic data appear to be symmetric with no outliers. The mean and the median are very close in value, which supports the assumption of symmetry. Because only five samples of the residual decontamination solution remaining in Tank WM-182 were collected, the five-number summary consists of all of the measurements that were taken. From this information, it can be seen that there are no outliers. Distributional assumptions, such as normality, will be discussed in Section 4.

Table 1. Organic constituents for which analyses of the tank residuals in WM-182 were performed.

Detected Volatile Organic Compounds		
acetone	toluene	2-butanone
Detected Semivolatiles		
phenol	tri-n-butyl phosphate	benzaldehyde[a]
Detected Polychlorinated Biphenyls		
none		
Undetected Volatile Organic Compounds		
benzene	1,2-dichlorobenzene	n nitrosodimethylamine
bromodichloromethane	1,3-dichlorobenzene	methylene chloride
bromoform	1,4-dichlorobenzene	styrene
bromomethane	1,1-dichloroethene	tetrachloroethylene
carbon disulfide	dichlorodifluoromethane	total xylene
carbon tetracholoride	1,2-dichloropropane	trans-1,2-dichloroethene
chlorobenzene	ethyl acetate	trans-1,3-dichloropropene
chloroethane	ethyl benzene	1,2,4-triclorobenzene
chloroform	2 hexanone	trichloroethene
chloromethane	isopropyl benzene	1,1,1 trichloroethane
cis-1,2-dichloroethene	m-xylene	1,1,2-trichloroethane
cis-1,3-dichloropropene	o-xylene	1,1,2,2-tetrachloroethane
cyclohexane	p-xylene	trichlorofluoromethane
cyclohexanone	methanol	1,1,2-trichloro-1,2,2-trifluoroethane
dibromochloromethane	methyl acetate	vinyl chloride
1,2-dibromoethane	methyl isobutyl ketone	
1,2-dibromo-3-chloropropane	methylcyclohexane	
Undetected Semivolatiles		
acenaphthene	4-chlorophenyl phenyl ether	isophorone
acenaphthylene	chrysene	2-methylnaphthalene
acetophenone	dibenzo(a,h)anthracene	2 methylphenol (o-cresol)
anthracene	dibenzofuran	4-methylphenol (p-cresol)
atrazine	3,3-dichlorobenzidine	naphthalene
benzo(a)anthracene	2,4 dichlorophenol	2 nitroaniline
benzo(a)pyrene	diethyl phthalate	3-nitroaniline
benzo(b)fluoranthene	dimethyl phthalate	4-nitroaniline
benzo(g,h,i)perylene	2,4 dimethylphenol	nitrobenzene
benzo(k)fluoranthene	di-n-butyl phthalate	2-nitrophenol
benzyl butyl phthalate	4,6-dinitro-2-methylphenol	4-nitrophenol
1,1’ biphenyl	2,4 dinitrophenol	n nitrosodimethylamine
bis-(2-chloroethoxy)methane	2,4 dinitrotoluene	n-nitrosodi-n-propylamine
bis-(2-chloroethyl)ether	2,6-dinitrotoluene	n-nitrosodiphenylamine
bis (2 ethylhexyl)phthalate	di-n-octyl phthalate	2,2’-oxybis(1 chloropropane)
4-bromophenyl phenyl ether	fluoroanthene	pentachlorophenol
caprolactam	fluorene	phenanthrene
carbazole	hexachlorobenzene	pyrene
2-chloronaphthalene	hexachlorobutadiene	pyridine
2-chlorophenol	hexachlorocyclopentadiene	2,4,5 trichlorophenol
4-chloro-3-methylphenol	hexachloroethane	2,4,6-trichlorophenol
4 chloroaniline	indeno(1,2,3-cd)pyrene	
Undetected Polychlorinated Biphenyls		
Aroclor-1016	Aroclor-1242	Aroclor-1254
Aroclor-1221	Aroclor-1248	Aroclor-1260
Aroclor-1232		

a. Benzaldehyde was detected in one sample. However, since only one detection was made, it is not possible to perform statistical analysis on the sample.

Table 2. Summary statistics for organic constituents detected in tank residuals in WM-182. Measurements are in µg/L.

Analyte	Mean	Median	Standard Deviation	Coefficient of Variation	Inter-quartile Range	Range
acetone	2.02E+02	2.02E+02	3.22E+01	1.59E+01	4.6E+01	7.8E+01
2-butanone	4.20E+02	4.47E+02	7.43E+01	1.77E+01	9.9E+01	1.79E+02
phenol	1.3E+01	3.1E+00	1.45E+01	1.11E+02	2.35E+01	2.95E+01
toluene	2.6E+00	2.4E+00	8.0E-01	3.14E+01	1.2E+00	1.9E+00
tri-n-butyl phosphate	1.8E+00	1.8E+00	2.0E-01	1.18E+01	3.0E-01	5.0E-01

Table 3. Five-number summary for organic constituents detected in tank residuals in WM-182. Measurements are in µg/L.

Analyte	Minimum Value	First Quartile	Median	Third Quartile	Maximum Value
acetone	1.60E+02	1.83E+02	2.02E+02	2.29E+02	2.38E+02
2-butanone	3.16E+02	3.72E+02	4.47E+02	4.71E+02	4.95E+02
phenol	1.6E+00	2.9E+00	3.1E+00	2.64E+01	3.11E+01
toluene	1.8E+00	1.9E+00	2.4E+00	3.1E+00	3.7E+00
tri-n-butyl phosphate	1.5E+00	1.6E+00	1.8E+00	1.9E+00	2.0E+00

3.1.2 Metals

Table 4 presents a list of metals for which analyses were conducted for the tank residuals and identifies whether or not each measured analyte was detected. In Table 5, the measures of central tendency and spread for metals are listed. Table 6 provides the five-number summary for each of the detected analytes.

Both lead and thallium were detected in only one sample. The detected value for lead was 5.5 µg/L. Because its action level is 4000 µg/L, it can be confidently concluded that the mean concentration of lead does not exceed its associated action level. The detected value for thallium was 5.5 µg/L and its corresponding action level is 26000 µg/L. Therefore, neither lead nor thallium will be included in the tables of summary statistics for detected metals.

The data for several of the analytes indicate that they have skewed distribution. Aluminum, cadmium, calcium, iron, manganese, mercury, and zinc all have a skewed distribution with zinc showing the greatest degree of asymmetry. The box plots constructed using the data produced from measurements for these analytes are helpful in assessing the degree of asymmetry (see Appendix A). The impact of this characteristic (i.e., a skewed distribution) of the data on the use of hypothesis tests will be discussed in Section 4. Although the data are skewed, none of the data points are extreme enough to be considered outliers given the sample size.

3.1.3 Anions

Table 7 presents a list of anions that were measured in the tank residuals and identifies whether or not each measured anion was detected. Table 8 presents measure of central tendency and spread for anions. Table 9 provides the five-number summary for each of the detected anions.

These summary statistics show that the data for the anions are symmetric with the exception of fluoride. None of the anions appear to have outliers. The asymmetry of fluoride will be further examined in Section 5.

Table 4. Metals constituents for which analyses of the tank residuals in WM-182 were performed.

Detected analytes	aluminum, barium, cadmium, calcium, chromium, copper, iron, lead,[a] magnesium, manganese, mercury, nickel, potassium, sodium, thallium,[a] zinc
Undetected analytes	antimony, arsenic, cobalt, beryllium, molybdenum, selenium, silver, vanadium

a. Lead and thallium were each detected in only one of the five samples. However, since only one detection was made, it is not possible to perform statistical analysis on the data.

Table 5. Summary statistics for metals detected in tank residuals in WM-182. Measurements are in µg/L.

Analyte	Mean	Median	Standard Deviation	Coefficient of Variation	Inter-quartile Range	Range
aluminum	5.61E+01	5.31E+01	1.81E+01	3.23E+01	7.9E+00	4.74E+01
barium	3.8E+00	3.6E+00	7.2E-01	1.88E+01	1.0E+00	1.7E+00
cadmium	1.10E+01	1.00E+01	3.3E+00	2.97E+01	2.7E+00	8.4E+00
calcium	4.18E+02	2.85E+02	2.57E+02	6.15E+01	2.29E+02	6.26E+02
chromium	1.7E+00	1.2E+00	8.0E-01	4.68E+01	1.3E+00	1.6E+00
copper	5.4E+00	3.5E+00	4.4E+00	8.16E+01	5.3E+00	1.06E+01
iron	1.5E+01	1.29E+01	7.4E+00	4.92E+01	3.2E+00	1.96E+01
magnesium	7.32E+01	5.88E+01	2.86E+01	3.91E+01	4.4E+01	6.31E+01
manganese	9.7E+00	6.9E+00	5.9E+00	6.11E+01	4.0E+00	1.49E+01
mercury	3.14E+01	3.08E+01	1.98E+01	6.31E+01	1.38E+01	5.16E+01
nickel	6.7E+00	5.8E+00	3.5E+00	5.25E+01	4.2E+00	8.8E+00
potassium	1.30E+03	1.10E+03	5.01E+02	3.85E+01	6.30E+02	1.22E+03
sodium	1.83E+03	1.47E+03	7.49E+02	4.11E+01	8.00E+02	1.87E+03
zinc	4.7E+00	3.1E+00	3.9E+00	8.27E+01	1.0E+00	9.2E+00

Table 6. Five-number summary of metals detected in tank residuals in WM-182. Measurements are in µg/L.

Analyte	Minimum Value	First Quartile	Median	Third Quartile	Maximum Value
aluminum	3.92E+01	4.69E+01	5.31E+01	5.48E+01	8.66E+01
barium	2.9E+00	3.5E+00	3.6E+00	4.5E+00	4.6E+00
cadmium	7.8E+00	9.1E+00	1.0E+01	1.18E+01	1.62E+01
calcium	2.11E+02	2.64E+02	2.85E+02	4.93E+02	8.37E+02
chromium	9.0E-01	1.2E+00	1.2E+00	2.5E+00	2.5E+00
copper	1.6E+00	2.3E+00	3.5E+00	7.6E+00	1.22E+01
iron	7.7E+00	1.20E+01	1.29E+01	1.52E+01	2.73E+01
magnesium	4.19E+01	5.80E+01	5.88E+01	1.02E+02	1.05E+02
manganese	4.6E+00	6.7E+00	6.9E+00	1.07E+01	1.95E+01
mercury	1.17E+01	1.87E+01	3.08E+01	3.25E+01	6.33E+01
nickel	3.1E+00	4.3E+00	5.8E+00	8.5E+00	1.19E+01
potassium	7.77E+02	1.00E+03	1.10E+03	1.63E+03	2.00E+03
sodium	1.05E+03	1.45E+03	1.47E+03	2.25E+03	2.92E+03
zinc	2.5E+00	2.7E+00	3.1E+00	3.7E+00	1.17E+01

Table 7. Anions for which analyses of the tank residuals in WM-182 were performed.

Detected anions	chlorine, fluoride, nitrate, sulfate
Undetected anions	phosphate

Table 8. Summary statistics for anions detected in tank residuals in WM-182. Measurements are in µg/L .

Analyte	Mean	Median	Standard Deviation	Coefficient of Variation	Inter-quartile Range	Range
chloride	1.4E+02	1.2E+02	6.0E+01	4.2E+01	6.0E+01	1.5E+02
fluoride	6.E+01	5.E+01	2.E+01	4.1E+01	2.E+01	6.E+01
nitrate	3.9E+03	3.78E+03	9.1E+02	2.3E+01	1.00E+03	2.35E+03
sulfate	8.3E+03	8.13E+03	1.15E+03	1.4E+01	1.50E+02	3.14E+03

Table 9. Five-number summary for anions detected in tank residuals from WM-182. Measurements are in µg/L.

Analyte	Minimum Value	First Quartile	Median	Third Quartile	Maximum Value
chloride	6.6E+01	1.2E+02	1.2E+02	1.8E+02	2.2E+02
fluoride	3.9E+01	4.E+01	5.E+01	6.E+01	9.6E+01
nitrate	2.8E+3	3.5E+03	3.78E+03	4.50E+03	5.15E+03
sulfate	7.1E+03	8.05E+03	8.13E+03	8.2E+03	1.024E+04

3.1.4 Analysis of pH

The pH of the samples collected from the Tank WM-182 post-decontamination residuals were also measured. The data in Tables 10 and 11 show the summary statistics and the five-number summary for the pH measurements.

It is apparent from the five-number summary of pH that the data are skewed. The maximum value is notably higher than the other pH measurements, but since there are only five measurements it cannot be concluded that the high-point is an outlier rather than evidence of an asymmetric distribution.

Table 10. Summary statistics for pH of tank residuals in WM-182.

	Mean	Median	Standard Deviation	Coefficient of Variation	Inter-quartile Range	Range
pH	3.98E+00	3.90E+00	2.00E-01	5.11E+00	8.00E-02	5.20E-01

Table 11. Five-number summary for pH of tank residuals in WM-182.

	Minimum Value	First Quartile	Median	Third Quartile	Maximum Value
pH	3.81E+00	3.88E+00	3.90E+00	3.96E+00	4.33E+00

3.1.5 Radionuclides

There are no specific action levels relative to the activity (i.e., concentrations) for the radionuclides left in any one tank following decontamination. Rather, the total inventory of radionuclides remaining in all closed components of the TFF will be of concern following completion of the TFF decontamination efforts. The PA conducted to address the DOE Order 435.1 closure requirements provides an estimate of an acceptable radionuclide concentration in the liquids remaining in each tank following decontamination. While these modeled levels are not the basis for a decision such as continuing to clean a tank, they provide a basis for comparison of the modeled value required to meet DOE closure standards and what is being achieved through decontamination efforts. Because of this, hypothesis testing is not required for making decisions concerning whether decontamination of Tank WM-182 may cease, but hypothesis testing using the modeled value as though it were an action level provides information on the decontamination effort for radionuclide.

Summary statistics were generated for the radionuclide data. Table 12 lists the radionuclides for which analyses were conducted in the rinsate from Tank WM-182 and differentiates between radionuclides that were detected and those that were not present at detectable levels. Table 13 provides a statistical summary of the detected radionuclide data and Table 14 provides the five-number summary for each of the detected radionuclides. For analytes that had some measurements below the detection limit, one-half of the detection-limit (i.e., the minimum detectable activity) was used in the calculations.

It should be noted that the originally technetium-99 results were obtained by a radiochemistry method that does not meet the detection limits required by the SAP and the method is subject to interferences due to the activity level of the sample. The samples were re-analyzed using an inductively coupled plasma-mass spectrometry (ICP-MS) method that meets the required detection limits. The ICP-MS results are included in this revision of the report.

Table 12. Radionuclides analyzed for in the tank residuals of WM-182.

Detected Analytes		
americium-241	iodine-129	ruthenium-103
antimony-125	neptunium-237	technetium-99
carbon-14	plutonium-238	total strontium
cesium-134	plutonium-239	tritium
cesium-137	plutonium-241	uranium-234
europium-154		
Undetected Analytes		
cerium-144	manganese-54	silver-108m
curium-242	niobium-94	silver-110m
curium-244	niobium-95	uranium-235
cobalt-58	nickel-63	uranium-236
cobalt-60	radium-226	uranium-238
europium-152	ruthenium-106	zinc-65
europium-155	silver-108m	zirconium-95

Table 13. Summary statistics for radionuclides detected in WM-182 liquid tank residuals. Measurements are in pCi/L.

Analyte	Mean	Median	Standard Deviation	Coefficient of Variation	Inter-quartile Range	Range
americium-241	5.48E+04	2.80E+04	5.62E+04	1.03E+02	6.37E+04	1.33E+05
antimony-125	2.42E+06	2.38E+06	1.99E+06	8.23E+01	1.92E+06	5.21E+06
carbon-14	6.78E+00	5.60E+00	4.25E+00	6.27E+01	4.76+00	1.09E+01
cesium-134	1.89E+05	1.44E+05	1.59E+05	8.38E+01	1.96E+05	3.92E+05
cesium-137	1.99E+08	1.96E+08	9.54E+07	4.80E+01	1.55E+08	2.21E+08
europium-154	3.87E+04	3.37E+04	1.80E+04	4.65E+01	2.11E+04	4.55E+04
iodine-129	1.51E+02	1.72E+02	7.74E+01	5.13E+01	1.06E+02	1.83E+02
neptunium-237	4.45E+01	4.32E+01	1.04E+01	2.35E+01	8.90E+00	2.81E+01
plutonium-238	3.51E+05	3.05E+05	1.95E+05	5.55E+01	1.12E+05	5.34E+05
plutonium-239	3.24E+04	2.94E+04	1.74E+04	5.36E+01	1.07E+04	4.77E+04
plutonium-241	1.76E+05	1.70E+05	1.57E+04	8.90E+00	1.30E+04	4.10E+04
ruthenium-103	5.42E+04	5.20E+04	1.53E+04	2.82E+01	7.60E+03	3.94E+04
technetium-99[a]	2.13E+04	1.38E+04	2.27E+04	1.07E+02	6.30E+03	5.95E+04
technetium-99[b]	4.87E+03	2.44E+03	4.44E+03	9.12E+01	5.70E+03	1.04E+04
total strontium	5.13E+07	4.71E+07	1.07E+07	2.09E+01	6.00E+06	2.79E+07
tritium	4.31E+03	4.20E+03	1.62E+03	3.81E+01	1.14E+03	4.08E+03
uranium-234	2.25E+02	1.70E+02	2.25E+02	1.00E+02	7.15E+01	5.60E+02

a. The technetium-99 results by a radiochemistry method.
b. The technetium-99 results by ICP-MS.

Table 14. Five-number summary for radionuclides detected in WM-182 liquid tank residuals. Measurements are in pCi/L.

Analyte	Minimum Value	First Quartile	Median	Third Quartile	Maximum Value
americium-241	1.05E+04	1.44E+04	2.80E+04	7.81E+04	1.43E+05
antimony-125	1.37E+05[a]	1.15E+06	2.38E+06	3.07E+06	5.35E+06
carbon-14	1.52E+00[a]	4.80E+00	5.60E+00	9.56E+00	1.24E+01
cesium-134	2.76E+04	7.98E+04	1.44E+05	2.76E+05	4.20E+05
cesium-137	9.25E+07	1.18E+08	1.96E+08	2.73E+08	3.13E+08
europium-154	1.86E+04[a]	2.80E+04[a]	3.37E+04[a]	4.91E+04[a]	6.40E+04
iodine-129	7.00E+01	7.67E+01	1.72E+02	1.83E+02	2.53E+02
neptunium-237	3.06E+01[a]	4.05E+01	4.32E+01	4.94E+01	5.87E+01
plutonium-238	1.01E+05	3.01E+05	3.05E+05	4.13E+05	6.35E+05
plutonium-239	9.10E+03	2.80E+04	2.94E+04	3.87E+04	5.68E+04
plutonium-241	1.59E+05	1.70E+05	1.70E+05	1.83E+05	2.00E+05
ruthenium-103	4.06E+04[a]	4.54E+04	5.20E+04[a]	5.30E+04[a]	8.00E+04[a]
technetium-99[b]	4.02E+02[a]	1.3+04	1.38E+04	1.93E+04	5.99E+04
Technetium-99[c]	7.80E+02	2.12E+03	2.44E+03	7.82E+03	1.12E+04
total strontium	4.11E+07	4.67E+07	4.71E+07	5.27E+07	6.90E+07
tritium	2.91E+03	3.15E+03	4.20E+03	4.29E+03	6.99E+03
uranium-234	5.85E+01[a]	1.03E+02[a]	1.70E+02[a]	1.74E+02[a]	6.18E+02[a]

a. Result was below the detection limit. Reported value is one-half of the detection limit.
b. Results by a radiochemistry method.
c. Results by ICP-MS.

4. STATISTICAL TEST SELECTION

Once the preliminary data review has been completed, an appropriate statistical hypothesis test may be selected. An appropriate statistical test is selected by finding the tests that are applicable to answering the question(s) for which the data were collected and by analyzing the data to determine if the data meets the assumptions of the desired test or tests. One of the primary requirements of many hypothesis tests is that the data follow a normal distribution. Tests that require the assumption of normality are generally more efficient than non-parametric tests (i.e., tests that do not have a distributional assumption). That is, a test that requires the data to be normally distributed can provide more accurate and reliable answers with fewer data points than a test that does not require the data to conform to a specific distribution. Non-parametric tests are most appropriate if the data do not follow a normal distribution. Because of the desirability to use a test that requires a normal distribution, if the data do not demonstrate a normal distribution they can be transformed. If the transformed data are normally distributed parametric methods can be performed on the transformed data. Although they do not require the data to exhibit a normal distribution, most non-parametric hypothesis tests also have assumptions that must be met. One of the most common assumptions for non-parametric tests is the data are symmetric. The assumptions of a selected hypothesis test, whether parametric or non-parametric, must be verified before the test is performed on the data.

The primary question to be answered in relation to Tank WM-182 is: does the mean concentration of any constituent of concern exceed the specified action level? This is a test that compares the sample mean to a constituent-specific action level. There are three primary tests that are appropriate for answering this type of question: the one sample z-test, student's one sample t-test, and the Wilcoxon signed rank test. The z-test requires knowledge of the population standard deviation (σ) and it requires that the data follow a normal distribution. Since the population standard deviation for each constituent concentration in the post-decontamination contents of Tank WM-182 is not known, the z-test will not be considered further. The t-test allows the use of calculated sample standard deviation (s) which is an estimate of σ. The t-test also requires that the data follow an approximate normal distribution unless the sample size is very large (much larger than the 5 samples collected in this case). The Wilcoxon signed rank test is a non-parametric test that compares a sample mean to an action level and does not require the data to follow a normal distribution. The primary assumption for this test is that the data are symmetric. If the data are analyzed and it is found that the data have neither a normal distribution nor are symmetric, the data may be transformed. Data are transformed by performing the same operation on each data point (such as taking the natural logarithm of each observation). If the transformed data have a normal distribution or are symmetric, then the appropriate test can be performed on the transformed data. If it is desired to calculate the UCL of an analyte for which the data has been transformed, the UCL can be calculated using the transformed data. The AL can then be transformed using the same function and directly compared to the UCL within the transformed space.

Because the t-test allows use of the sample standard deviation (s) and is a very powerful test for small data sets, the t-test was chosen as the most desirable means for testing the null hypothesis. After selecting a statistical test, it is necessary to verify the assumptions of the test selected. These assumptions are examined in Section 5.

5. VERIFICATION OF THE ASSUMPTIONS FOR THE SELECTED HYPOTHESIS TEST

This section examines the underlying assumptions of the statistical hypothesis test in light of the data collected. In order to select the appropriate test, the distributions of the data obtained for each analyte need to be evaluated. Because tests that require the data to be normally distributed can provide more accurate and reliable answers with fewer data points (e.g., five samples), it is preferred to use a test that requires the data to be normal. Thus, it must first be determined if the data follow a normal distribution or if they can be transformed to follow a normal distribution. This is done using graphical methods such as histograms and normal-quantile plots. There are statistical tests, such as the Shapiro-Wilk W test or the χ^2 test for distributions that can be used to determine if the data follow a normal distribution, but they have their limitations. If there are a small number of data points, it is difficult for distributional tests to detect deviations from normality in the data. However, standard deviations are small compared to the action levels and observed concentrations are less than the action levels to such a degree that five samples are adequate for confidently declaring tank WM-182 sufficiently clean for closure. However, if the data set is large, even data that is very close to normal in distribution may not pass the test. In the analysis of Tank WM-182 rinsate, graphical methods were primarily used to assess normality and the Shapiro-Wilk W test was also used to assess normality. The graphical representations of the data were prepared using S-Plus 2000 software (Mathsoft 2000). The Shapiro-Wilk W test calculations were performed using DataQUEST software (EPA 1997). Since only five samples were taken from the tank, histograms were not very useful. Normal-quantile plots were the primary graphical method used to evaluate whether the data exhibited a normal distribution. These plots are presented in the appendices of this report. The assessment of normality of the data is discussed in the following sections.

Since the primary objective of this DQA analysis is to determine if the mean concentration of a specified analyte is less than its associated action level, criteria have been developed in dealing with deviations from normality. If the Shapiro-Wilk test indicates that the data are normally distributed at the $\alpha = 0.05$ level and the summary statistics and plots indicate that the data are symmetric, then the *t*-test will be performed on the raw data. If the Shapiro-Wilk test conclusively shows that the data are normally distributed (the p-value is comfortably greater than 0.05), but the box plot and other summary statistics indicate that the data might be right-skewed, then the raw data will be used for the *t*-test. However, if the data in this situation fail the *t*-test, a transformation that can make the data closer to normal in distribution will be sought and the test will be redone. If the p-value for the Shapiro-Wilk test is close to or less than 0.05 and the data are left-skewed, then a transformation will be sought to bring the distribution into the acceptable range of normality. If the data are right-skewed and the p-value for the Shapiro-Wilk test is less than 0.05 indicating that the data are non-normal, then an appropriate transformation will be sought for the data. If an appropriate transformation cannot be found then the data will be analyzed on a case-by-case basis to determine if it appears that the action level has been exceeded. This will also be done if the data are left-skewed and a suitable transformation cannot be found.

5.1 Normality of Organic Constituent Data

Normal-quantile plots were constructed for each of the five detected organic constituents. A normal-quantile plot is read by evaluating how close the data points fall to the line displayed on the plot. If the data points display a good fit to the line, they are assumed to be normally distributed. Each of the normal quantile plots constructed for the organic constituent data show that the data are very close to normal in distribution. It appears from the plots that the normality assumption required for use of the *t*-test was met for these data. The Shapiro-Wilk W test was also done using the data collected for each of these analytes. The W test is an effective method for testing whether a data set has been drawn from an underlying normal distribution. The test involves a calculation that results in a sample value variable (W).

To determine if the data show a normal distribution at specified level of significance the value of W is compared to a tabulated value developed by Shapiro and Wilk. The value from the table represents the quantile for data that are normal at the given level of significance. If the calculated value of W is greater than the quantile given in the table for the given level of significance, then the null hypothesis for the test (i.e., the underlying data set exhibits a normal distribution) cannot be rejected. The results of the W test for the organic constituent data are shown in Table 15. This test also demonstrates that the organic constituent data are normal in distribution. From this information it can be concluded that the *t*-test is appropriate for analyzing the detected organic constituents.

5.2 Normality of the Metals Data

Detected metals data were also analyzed using normal-quantile plots and the Shapiro-Wilk test. Normal-quantile plots indicate that the data for aluminum, cadmium, calcium, iron, manganese, mercury, and zinc are right skewed. Zinc shows the most marked degree of asymmetry. Several transformations were used in an attempt to obtain data that were closer to normal in distribution. Most of these constituents were transformed using the transformation *1/ln(x)*. The Shapiro-Wilk test was done on the untransformed data. Table 16 contains the results of the Shapiro-Wilk test for the metals constituents.

Table 15. Results of the Shapiro-Wilk W test for assessing if the organic constituents follow a normal distribution.

	5% Significance level			1% Significance level		
Analyte	Sample Value (W)	Table Value	Non-Normal	Sample Value (W)	Table Value	Non-Normal
acetone	0.995	0.762	No	0.995	0.686	No
2-butanone	0.924	0.762	No	0.924	0.686	No
phenol	0.763	0.762	No	0.763	0.686	No
toluene	0.917	0.762	No	0.917	0.686	No
tri-n-butyl phosphate	0.952	0.762	No	0.952	0.686	No

Table 16. Results of the Shapiro-Wilk W test for assessing if the inorganic constituents follow a normal distribution.

	5% Significance level			1% Significance level		
Analyte	Sample Value (W)	Table Value	Non-Normal	Sample Value (W)	Table Value	Non-Normal
aluminum	0.851	0.762	No	0.851	0.686	No
barium	0.909	0.762	No	0.909	0.686	No
cadmium	0.914	0.762	No	0.914	0.686	No
calcium	0.837	0.762	No	0.837	0.686	No
chromium	0.786	0.762	No	0.786	0.686	No
copper	0.88	0.762	No	0.88	0.686	No
iron	0.873	0.762	No	0.873	0.686	No
magnesium	0.844	0.762	No	0.844	0.686	No
manganese	0.844	0.762	No	0.844	0.686	No
mercury	0.902	0.762	No	0.902	0.686	No
nickel	0.945	0.762	No	0.945	0.686	No

Table 16. (continued).

Analyte	5% Significance level Sample Value (W)	Table Value	Non-Normal	1% Significance level Sample Value (W)	Table Value	Non-Normal
potassium	0.928	0.762	No	0.928	0.686	No
sodium	0.919	0.762	No	0.919	0.682	No
zinc	0.658	0.762	Yes	0.658	0.686	Yes
zinc (with 1/ln(x) transformation)	0.921	0.762	No	0.921	0.686	No

The only analyte that the W test determined was significantly non-normal in distribution is zinc. The zinc data was transformed using the *1/ln(x)* transformation. Transformations (a single function applied to each data value) can be used to make non-normal data suitable for use with the *t*-test. The W test was run again for the zinc data after they were transformed. The transformed zinc data were determined to be sufficiently normal in distribution. The results of the Shapiro-Wilk test indicate it is more appropriate to use the *t*-test on the transformed zinc data.

Even though the normal-quantile plots for aluminum, cadmium, calcium, iron, manganese, and mercury show that the data are right skewed, the W test results for these analytes do not indicate the data are drawn from a distribution that is not normal at the significance levels tested. Also, the direction of the asymmetry of the data for these metals would bias a *t*-test in such a way that it will be more difficult to show that the data do not exceed the specified action levels. Hence, a *t*-test will be used on the untransformed data of the detected metals with the exception of zinc. This will result in a bias toward concluding the concentration of a constituent exceeds the action level. If any of the *t*-tests for aluminum, cadmium, calcium, iron, manganese, or mercury show that the concentration of an analyte is not lower than the action level, then the test will be redone using transformed data since this would allow the *t*-test to be used on a normally distributed data set which is an assumption for using this test. If the *t*-test using the untransformed data does not indicate an action level is exceeded, it would not show an action level exceeded on the transformed data either due to the bias mentioned earlier.

5.3 Normality of the Anions Data

Detected anions were analyzed using normal-quantile plots and the Shapiro-Wilk W test. Normal-quantile plots show asymmetry in the fluoride data. The plots also indicate that the data for sulfate are symmetrical, but not normal in distribution. The Shapiro-Wilk W test was done on untransformed data for all anions. Table 17 contains the results of the Shapiro-Wilk W test for the anions data. The W test also indicates that the data are sufficiently normal in distribution for use of the *t*-test. From this, it was concluded that the *t*-test is appropriate for use with untransformed anions data.

Table 17. Results of the Shapiro-Wilk test for assessing if the anions follow a normal distribution.

Analyte	5% Significance level Sample Value (W)	Table Value	Non-Normal	1% Significance level Sample Value (W)	Table Value	Non-Normal
chlorine	0.957	0.762	No	0.957	0.686	No
fluoride	0.832	0.762	No	0.832	0.686	No
nitrate	0.968	0.762	No	0.986	0.686	No
sulfate	0.851	0.762	No	0.851	0.686	No

5.4 Normality of the pH Data

Normality was also assessed for the pH data. The normal-quantile plot showed that there may be some concerns with the normality of the data. The Shapiro-Wilk W test results are included in Table 18. Results of the Shapiro-Wilk W test show that the data for pH are sufficiently normal to use the *t*-test for analyzing the pH data.

Table 18. Results of the Shapiro-Wilk test for assessing if the pH follows a normal distribution.

	5% Significance level			1% Significance level		
Analyte	Sample Value	Table Value	Non-Normal	Sample Value	Table Value	Non-Normal
pH	0.797	0.762	No	0.797	0.686	No

5.5 Normality of the Radionuclide Data

Detected radionuclides data were also analyzed using normal-quantile plots and the Shapiro-Wilk test. Normal-quantile plots show the data for tritium, ruthenium-103, original technetium-99 measurements, total strontium, and uranium-234 are right skewed. Of these radionuclides, uranium-234 shows the most pronounced degree of asymmetry. Several transformations were used in an attempt to obtain data that were closer to normal in distribution. Most of these constituents were transformed using the transformation *ln(x)*. The Shapiro-Wilk test was done on the untransformed data. Table 19 contains the results of the Shapiro-Wilk test for the radionuclides.

The only analyte that the W test determined was significantly non-normal in distribution is uranium-234. The W test was run again for the uranium-234 data after they were transformed using the *ln(x)* transformation. The transformed uranium-234 data were determined to be normal in distribution. The results of the Shapiro-Wilk test indicate it is more appropriate to use the *t*-test on the transformed uranium-234 data.

5.6 Verification of Standard Deviation Assumption

The SAP associated with this project assumed a standard deviation of 10% of the action level in order to estimate the sample size necessary to achieve the desired α and β. The ratio (standard deviation)/(action level) was measured for each detected analyte. The largest of these ratios was 0.017 (or 1.7%). This means that the chosen levels of α and β were in fact conservative estimates of true levels of α and β for this analysis.

Table 19. Results of the Shapiro-Wilk test for assessing if the radionuclides follow a normal distribution.

Analyte	5% Significance Level			1% Significance Level		
	Sample Value	Table Value	Non-Normal	Sample Value	Table Value	Non-Normal
americium-241	0.847	0.762	No	0.847	0.686	No
antimony-125	0.974	0.762	No	0.974	0.686	No
carbon-14	0.971	0.762	No	0.971	0.686	No
cesium-134	0.941	0.762	No	0.941	0.686	No
cesium-137	0.93	0.762	No	0.93	0.686	No
europium-154	0.963	0.762	No	0.963	0.686	No
iodine-129	0.906	0.762	No	0.906	0.686	No
neptunium-237	0.993	0.762	No	0.993	0.686	No
plutonium-238	0.962	0.762	No	0.962	0.686	No
plutonium-239	0.974	0.762	No	0.974	0.686	No
plutonium-241	0.937	0.762	No	0.937	0.686	No
ruthenium-103	0.84	0.762	No	0.84	0.686	No
technetium-99	0.82	0.762	No	0.82	0.686	No
technetium-99 by ICP-MS	0.872	0.762	No	0.872	0.686	No
total strontium	0.872	0.762	No	0.872	0.686	No
tritium	0.845	0.762	No	0.845	0.686	No
uranium-234	0.747	0.762	Yes	0.747	0.686	No
uranium-234 (with ln transformation)	0.942	0.762	No	0.942	0.686	No

6. CONCLUSIONS DRAWN FROM THE DATA

6.1 Performance of the Statistical Hypothesis Test

As discussed in the previous section, it was determined that the *t*-test may be appropriately applied to determine if the mean concentration of any constituent of concern exceeds its specified action level. The primary assumption of the *t*-test that must be met is that the data are normal in distribution. The review of the data relative to this distributional assumption was performed in Section 5 and it was concluded that the assumption was adequately met for all data.

The DQOs for the study chose a conservative statistic to estimate the population mean. Specifically, the decision statements for the project specify, "*If* the true mean (as estimated by the 95% UCL of the sample mean) concentration of any hazardous constituent…" These decision statements allow a simple comparison of the 95% UCL of the sample mean to the action level for the purposes of making a decision. The DQOs of the study also specify a desired rate for α of 5%. The confidence level for a UCL is equal to 1-α. This means that 95% of all UCLs generated from all samples of size 5 will be less than the action limit if, in fact, the concentration of the hazardous constituent in the tank is less than the action level. The 95% UCL can be thought of as a conservatively high estimate of the population mean. The comparison of the 95% UCL to the action level is a way of performing the *t*-test.

The UCL of the sample mean is calculated using Equation (6):

$$UCL = \bar{x} + t^*_{1-\alpha,df}\frac{s}{\sqrt{n}} \tag{6}$$

where

$\bar{x}$	=	sample mean
$t^*_{1-a,df}$	=	the *t*-statistic for degree of confidence (1 - α)*100% and degrees of freedom *df*. In this case the confidence is (1–0.05)*100% = 95% and the degrees of freedom = n–1 = 4. From statistical tables this corresponds to a value of 2.132 (or 2.776 for pH as explained below).
s	=	sample standard deviation
n	=	number of samples taken.

The 95% lower confidence limit (LCL) is also of importance to analyzing pH. Since pH has action levels for both high pH and low pH, it is necessary to determine if pH is less than the LCL. Since both the LCL and the UCL are of importance the *t*-value for the LCL and UCL will be determined with α/2 instead of α to ensure that the total probability of a false positive decision error occurring is α rather than 2*α. The LCL is compared to a pH of 2 to ensure that the true mean is greater than 2 at the specified degree of confidence. The LCL is calculated using Equation (7):

$$LCL = \bar{x} - t^*_{1-\alpha,df}\frac{s}{\sqrt{n}} \tag{7}$$

where

$\bar{x}$ = sample mean

$t^{*}_{1-\alpha,df}$ = the t-statistic for degree of confidence $(1 - \alpha)*100\%$ and degrees of freedom df. In this case the confidence is $(1–0.05)*100\% = 95\%$ and the degrees of freedom = n–1 = 4. From statistical tables this corresponds to a value of 2.776.

s = sample standard deviation

n = number of samples taken.

To conduct the t-test, the sample t-value is calculated using Equation (8):

$$t = (\bar{x} - C)/(s/\sqrt{n}) \tag{8}$$

where

$\bar{x}$ = sample mean

C = the constituent-specific action level.

s = sample standard deviation

n = number of samples taken.

The sample t-value is compared to the critical value $t_{1-\alpha,\, df}$ for degree of confidence α and degrees of freedom df (where $df = n$-1). For this study, the desired α has been specified at 5%. The critical value $t_{1-\alpha,\, df}$ for a 95% degree of confidence and 4 degrees of freedom is 2.132. Therefore, if the calculated sample t-value is less than -2.132, then the null hypothesis (i.e., the true mean concentration is greater than the action level) may be rejected and it can be determined with the degree of confidence specified that the action level has not been exceeded. In the case of pH measurements, the sample t-value is calculated using both the upper and lower action levels. For the lower action level (pH=2), the null hypothesis (i.e., pH<2) may be rejected if the sample t-value is greater than 2.776 and for the upper action level the null hypothesis (i.e., pH>12.5) may be rejected if the sample t-value is less than -2.776.

Table 20 contains the sample means, UCL used to estimate the population mean, calculated sample t-values, critical t-value, action level, and a decision about whether or not the action level may have been exceeded for each of the detected organic and inorganic constituents. Table 21 contains the sample mean, LCL and UCL used to estimate the population-mean, calculated sample t-values for comparing the mean to lower action level and upper action level, the critical t-values, action levels, and a decision about whether or not either action level may have been exceeded for pH. Table 22 provides the same information for radionuclides compared to the PA modeled inventory.

6.2 Conclusions

From Tables 20 and 21 it can be confidently stated that none of the concentrations of the constituents of concern exceed the specified action levels. Each of the constituents of concern were either not present at detectable levels in the rinsate or were present in levels that were below (or in the case of pH between) the specified action levels. For the radionuclide data, the activities were compared to the values that were modeled in the PA to be present in liquids remaining in the tanks after decontamination. These modeled levels are not action levels. Rather they are an indication of whether the assumptions for activities following decontamination are conservative. The data in Table 22 show that it can be confidently stated that the activities are less than the modeled values for all radionuclides except antimony-125.

Data were examined to determine if assumptions for using the *t*-test were met. Each constituent either clearly met the assumption of normality or was skewed in such a way that the data are biased against rejecting the null hypothesis that the action level is exceeded. The only RCRA-regulated constituent that needed to be transformed was zinc. The only radionuclide that required data transformation was uranium-234. All of the organic and inorganic constituents were present in the rinsate at concentrations that were significantly less than their action levels. Hence, the data provide a high degree of confidence in making a decision that the decontamination efforts were successful in reducing concentrations of RCRA-regulated constituents to below the action levels specified in the closure plan for Tanks WM-182 (DOE-ID 2003a). All of the radionuclides except antimony-125 were present in the rinsate at an activity that were significantly less than the activity modeled by the PA. Hence, the data provide a high degree of confidence in making a decision that the decontamination efforts were successful in reducing the activity of all radionuclides except antimony-125 to below those modeled in the closure plan for Tanks WM-182 (DOE-ID 2003a). Because antimony-125 is not a large dose contributor in the PA, it is believed that the residual activity attributable to this radionuclide in WM-182 will not result in an issue for the overall closure of the TFF once all tanks have been cleaned and characterized.

Table 20. Summary of post-decontamination concentrations of organic and inorganic constituents detected in the rinsate of Tank WM-182.

Constituent	Mean Concentration	95% UCL	Units	Sample *t*-value	Critical *t*-value	Action level	Level Exceeded?
acetone	2.02E+02	2.33E+02	µg/L	-6.9E+04	-2.132	9.9E+05	No
2-butanone	4.20E+02	4.91E+02	µg/L	-4.8E+03	-2.132	1.6E+05	No
phenol	1.3E+01	2.68E+01	µg/L	-3.7E+05	-2.132	2.4E+06	No
toluene	2.6E+00	3.35E+00	µg/L	-3.9E+06	-2.132	1.4E+06	No
tri-n-butylphosphate	1.8E+00	2.0E+00	µg/L	NA[a]	-2.132	NA	No
aluminum	5.61E+01	7.34E+01	µg/L	-3.8E+05	-2.132	3.1E+06	No
barium	3.8E+00	4.5E+00	µg/L	-2.6E+05	-2.132	8.3E+04	No
cadmium	1.1E+01	1.4E+01	µg/L	-4.1E+02	-2.132	6.1E+02	No
calcium	4.18E+02	6.63E+02	µg/L	NA	-2.132	NA	No
chromium	1.7E+00	2.4E+00	µg/L	-2.6E+03	-2.132	9.0E+02	No
copper	5.4E+00	9.7E+00	µg/L	-3.0E+05	-2.132	6.0E+05	No
flouride	6.0E+01	7.9E+01	µg/L	-7.4E+04	-2.132	7.7E+05	No
iron	1.5E+01	2.2E+01	µg/L	-5.1E+05	-2.132	1.7E+06	No
magnesium	7.32E+01	1.00E+02	µg/L	NA	-2.132	NA	No
manganese	9.7E+00	1.5E+01	µg/L	-1.8E+05	-2.132	4.9E+05	No
mercury	3.14E+01	5.03E+01	µg/L	-1.5E+01	-2.132	1.6E+02	No
nickel	6.7E+00	1.0E+01	µg/L	-2.8E+05	-2.132	4.4E+05	No
potassium	1.30E+3	1.78E+03	µg/L		-2.132		
sodium	1.83E+03	2.54E+03	µg/L	NA	-2.132	NA	No
zinc	4.7E+00	8.5E+00	µg/L	-9.7E+05	-2.132	1.7E+06	No
zinc (transformed)	8.31E-01	1.09E+00	µg/L	6.36E+00	-2.132	6.97E-02[b]	No
chloride	1.4E+02	2.0E+02	µg/L	NA	-2.132	NA	No
nitrate	3.90E+03	4.80E+03	µg/L	NA	-2.132	NA	No
sulfate	8.30E+03	9.40E+03	µg/L	NA	-2.132	NA	No

a. NA=Not applicable. An action level has not been specified. Therefore, the sample *t*-value cannot be calculated.

b. Since the transformation for zinc was of the 1/f(x) variety, the appropriate comparison of the transformed data is that if the UCL-transformed data are greater than the transformed AL, then the concentration of zinc is less than the AL.

Table 21. Summary of post-decontamination pH in the rinsate of Tank WM-182.

	Mean	95% LCL	95% UCL	Lower Sample *t*-value	Upper Sample *t*-value	Critical *t*-value	Lower Action level	Upper Action level	Action level Exceeded?
pH	3.98	3.72	4.23	21	-93	+/-2.776	2	12.5	No

Table 22. Summary of post-decontamination activities of radionuclides in the rinsate of Tank WM-182.

Constituent	Mean Concentration	95% UCL	Units	Sample *t*-value	Critical *t*-value	PA Modeled Inventory	Modeled Inventory Exceeded?
americium-241	5.48E+04	1.08E+05	pCi/L	-1.40E+03	-2.132	3.60E+07	No
antimony-125	2.42E+06	4.31E+06	pCi/L	1.00E+00	-2.132	1.49E+06	Yes
carbon-14	6.78E+00	1.08E+01	pCi/L	-5.21E+07	-2.132	9.90E+07	No
cesium-134	1.89E+05	3.41E+05	pCi/L	-1.40E+01	-2.132	1.21E+06	No
cesium-137	1.99E+08	2.89E+08	pCi/L	-2.69E+03	-2.132	1.15E+11	No
europium-154	3.87E+04	5.58E+04	pCi/L	-2.27E+04	-2.132	1.83E+08	No
iodine-129	1.51E+02	2.25E+02	pCi/L	-2.15E+03	-2.132	7.44E+04	No
neptunium-237	4.45E+01	5.44E+01	pCi/L	-7.30E+04	-2.132	3.43E+05	No
plutonium-238	3.51E+05	5.37E+05	pCi/L	-6.54E+03	-2.132	5.70E+08	No
plutonium-239	3.24E+04	4.90E+04	pCi/L	-9.07E+03	-2.132	7.05E+07	No
plutonium-241	1.76E+05	1.91E+05	pCi/L	-6.04E+04	-2.132	4.24E+08	No
ruthenium-103	5.42E+04	6.88E+04	pCi/L	NA[a]	-2.132	NA	No
technetium-99[b]	2.13E+04	4.29E+04	pCi/L	-2.95E+03	-2.132	2.99E+07	No
technetium-99[c]	4.87E+03	9.11E+03	pCi/L	-1.50E+04	-2.132	2.99E+07	No
total strontium	5.13E+07	6.15E+07	pCi/L	-1.70E+04	-2.132	8.15E+10	No
tritium	4.29E+03	5.85E+03	pCi/L	-2.22E+04	-2.132	1.61E+07	No
uranium-234	2.25E+02	4.39E+02	pCi/L	-2.50E+04	-2.132	2.52E+06	No
uranium-234 (with ln transformation)	5.09E+00	5.92E+00	pCi/L	-2.48E+01	-2.132	1.47E+01	No

a. NA=Not applicable. A post-decontamination activity was not modeled in the PA for this radionuclide in the liquid tank residuals. Therefore, a sample *t*-value cannot be calculated. The half-life of ruthenium-103 is only 39 days. Analytical error may be involved.

b. The technetium-99 results reported were obtained by a radiochemistry method that does not meet the detection limits required by the SAP and the method is subject to interferences due to the activity level of the sample. The samples are being re-analyzed using an ICP-MS method which should meet the required detection limits; the report will be revised based on the new analysis.

c. The technetium-99 results by ICP-MS.

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40 CFR 261.24, 2003, “Toxicity Characteristic,” *Code of Federal Regulations*, U.S. Environmental Protection Agency, Office of the Federal Register, National Archives and Records Administration, Online via http://www.access.gpo.gov, July 1, 2003.

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Appendix A

Metals

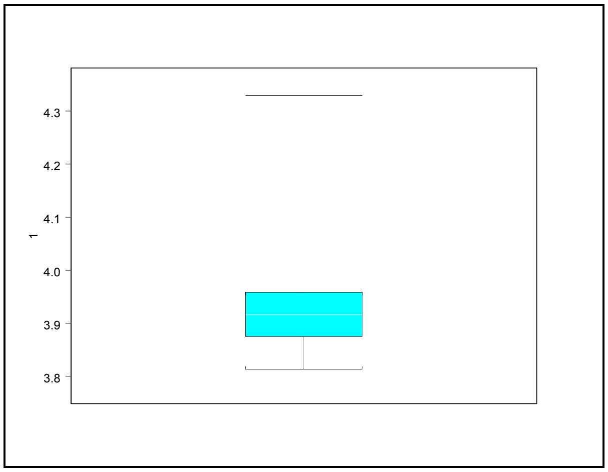


Figure 1. Box plot of aluminum data.

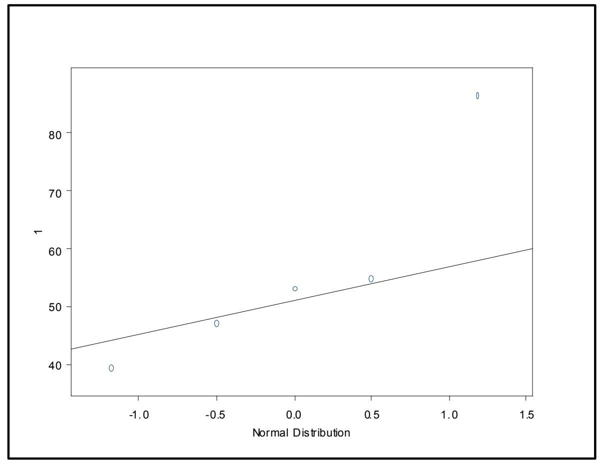


Figure 2. Normal-quantile plot of aluminum data.

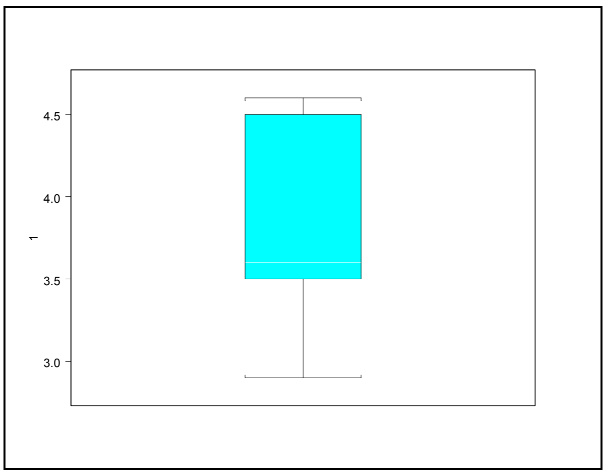


Figure 3. Box plot of barium data.

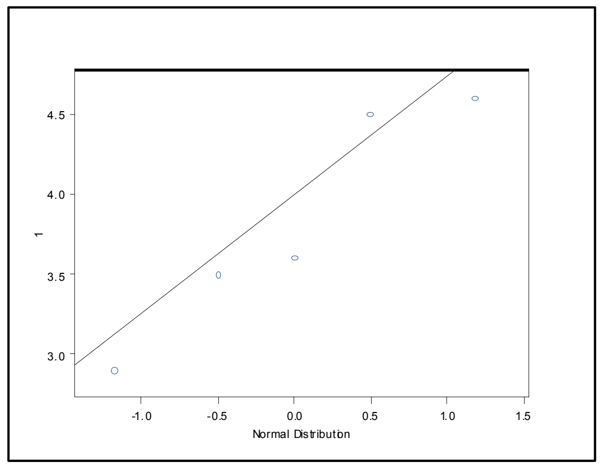


Figure 4. Normal-quantile plot of barium data.

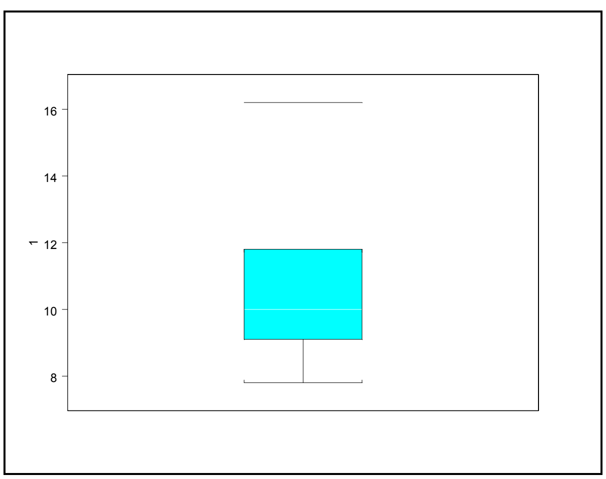


Figure 5. Box plot of cadmium data.

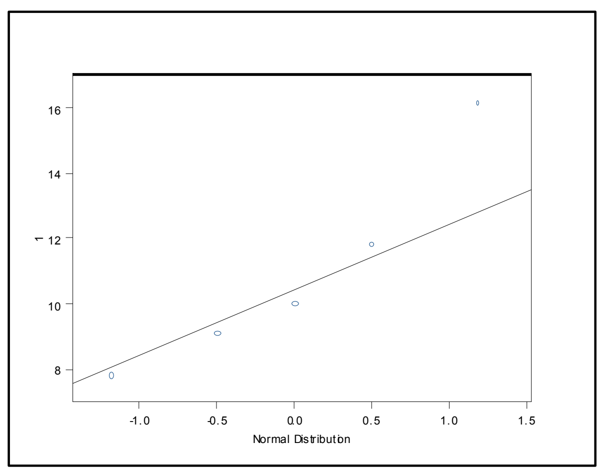


Figure 6. Normal-quantile plot of cadmium data.

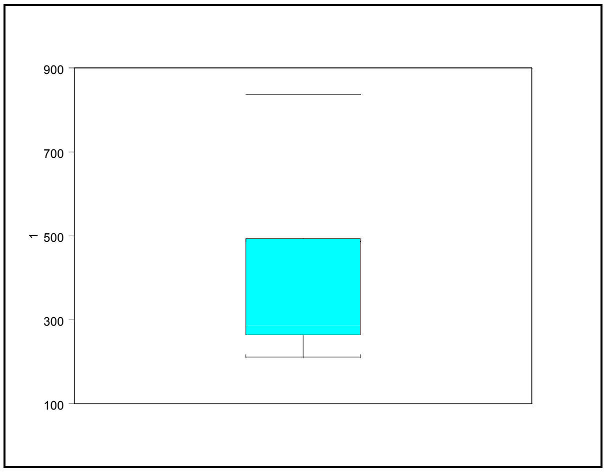


Figure 7. Box plot of calcium data.

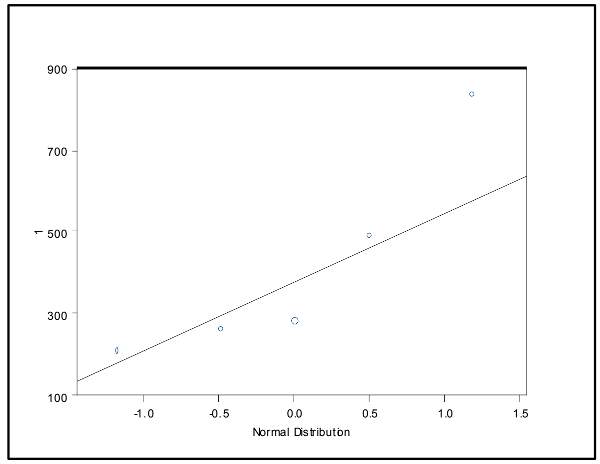


Figure 8. Normal-quantile plot of calcium data.

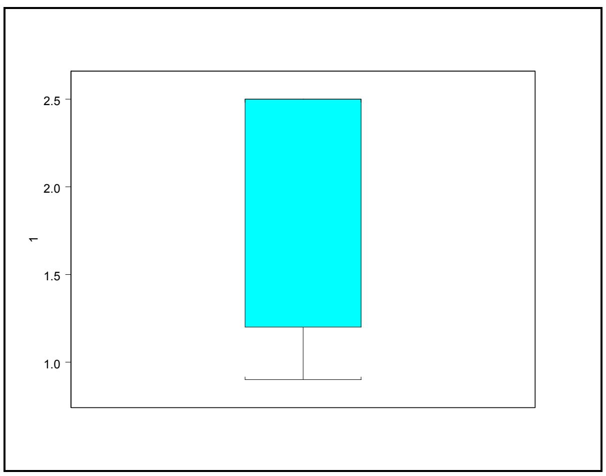


Figure 9. Box plot of chromium data.

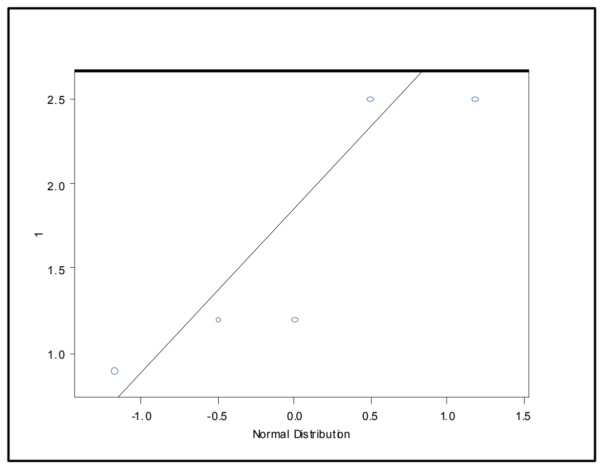


Figure 10. Normal-quantile plot of chromium data.

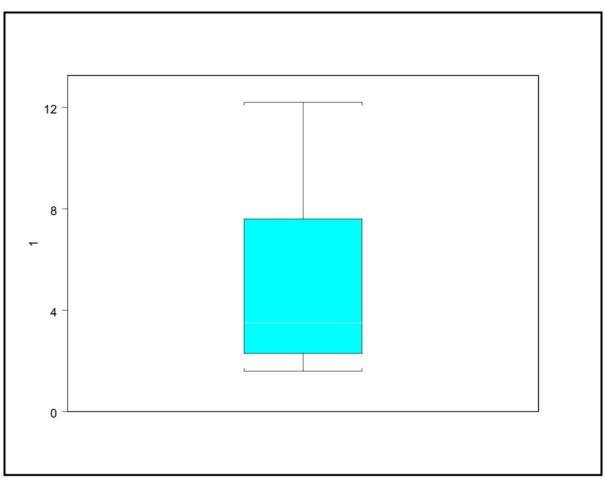


Figure 11. Box plot of copper data.

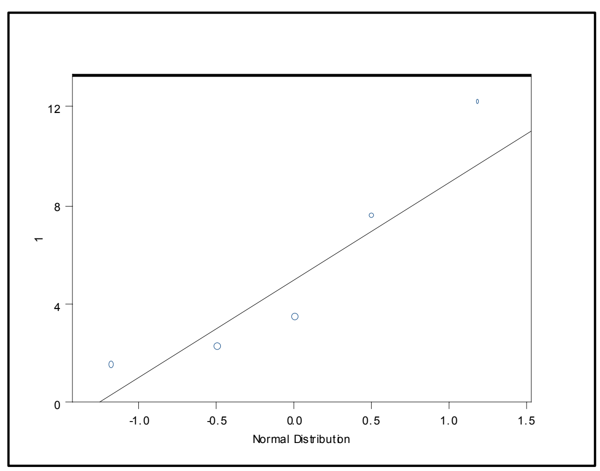


Figure 12. Normal-quantile plot of copper data.

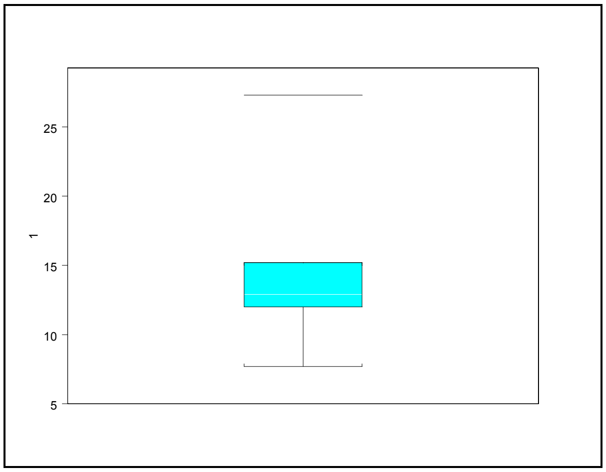


Figure 13. Box plot of iron data.

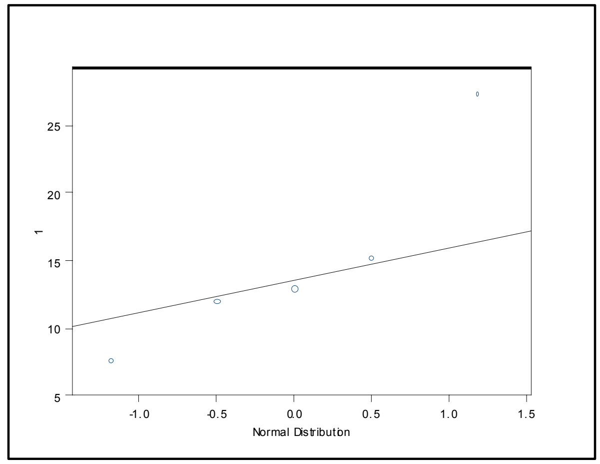


Figure 14. Normal-quantile plot of iron data.

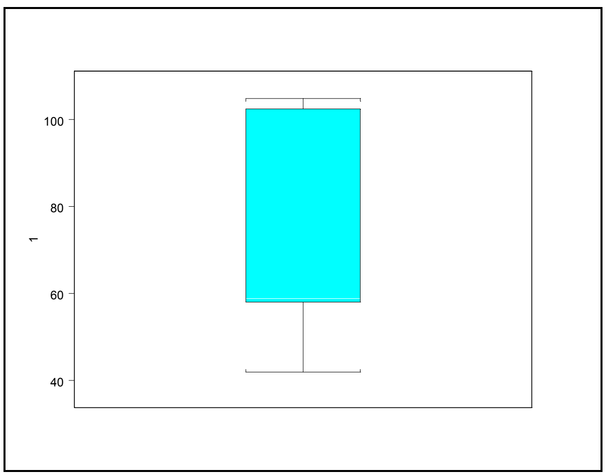


Figure15. Box plot of magnesium data.

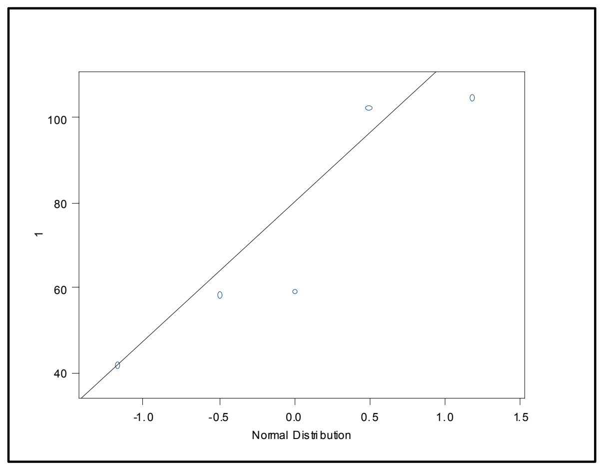


Figure 16. Normal-quantile plot of magnesium data.

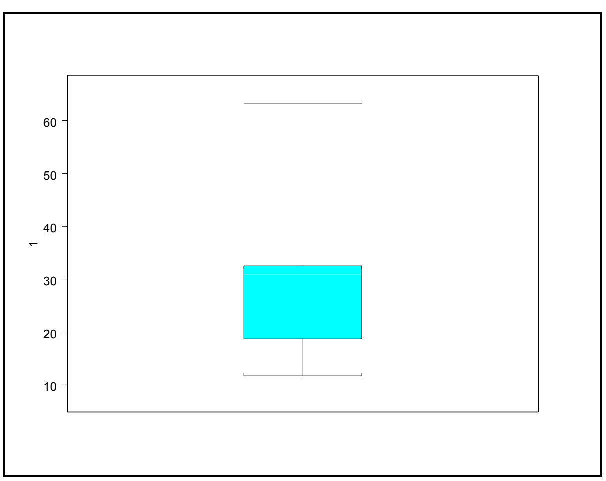


Figure 17. Box plot of mercury data.

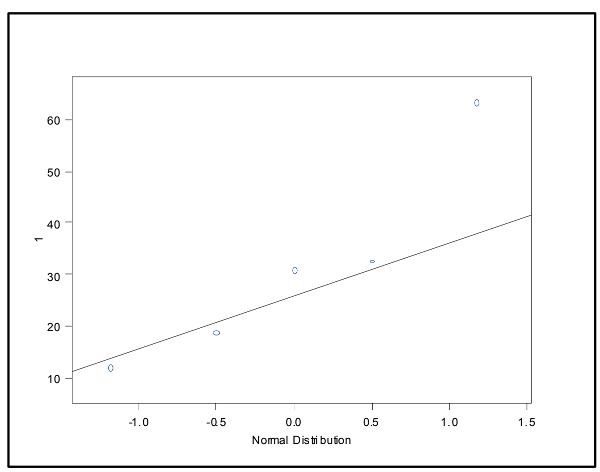


Figure 18. Normal-quantile plot of mercury data.

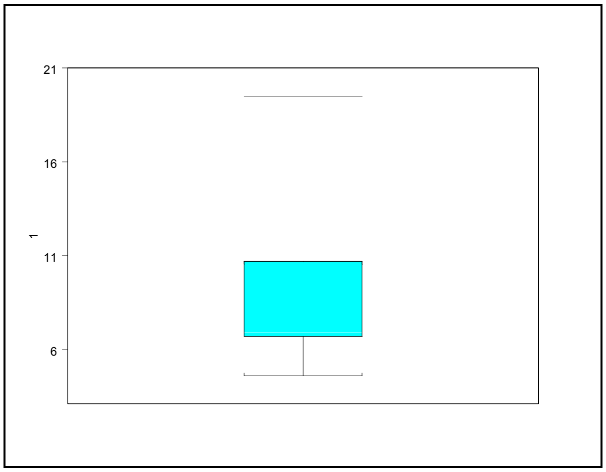


Figure 19. Box plot of manganese data.

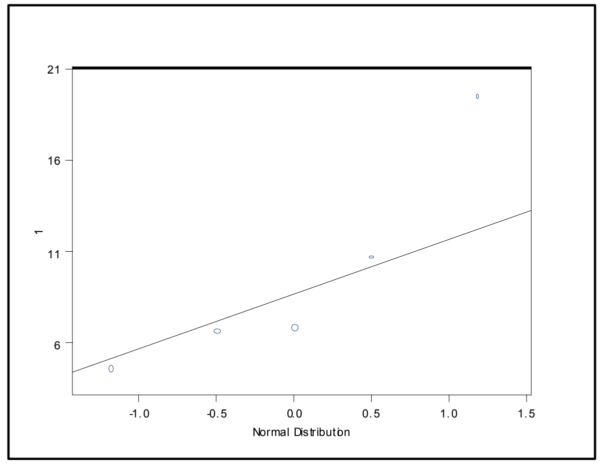


Figure 20. Normal-quantile plot of manganese data.

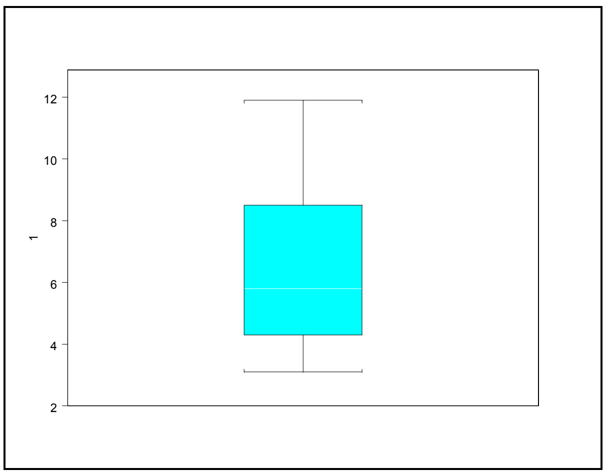


Figure 21. Box plot of nickel data.

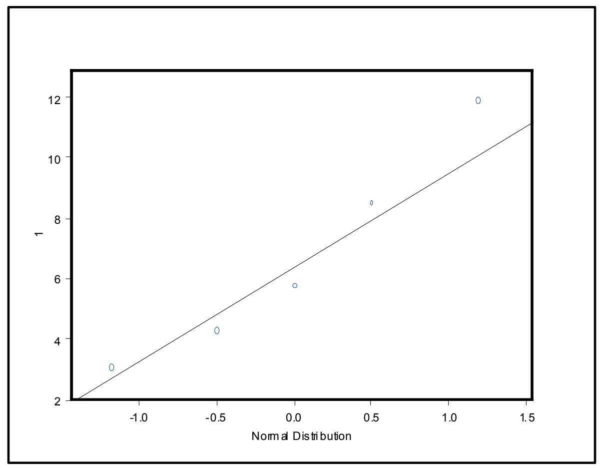


Figure 22. Normal-quantile plot of nickel data.

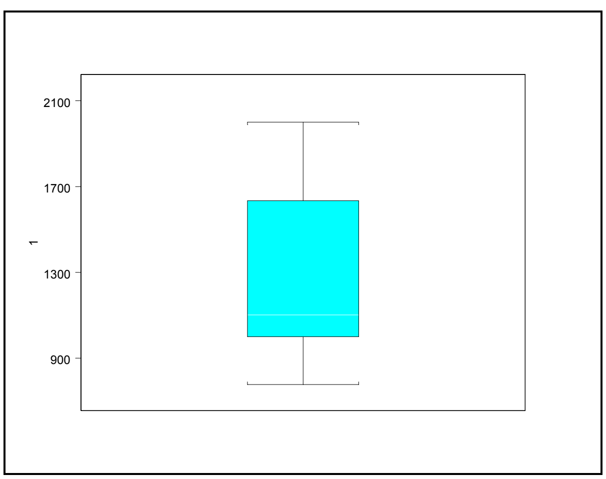


Figure 23. Box plot of potassium data.

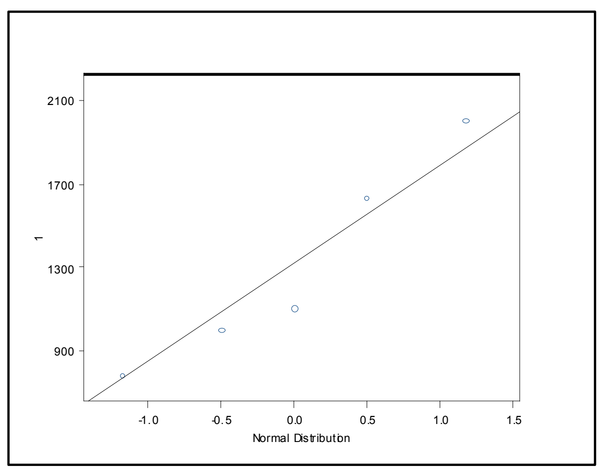


Figure 24. Normal-quantile plot of potassium data.

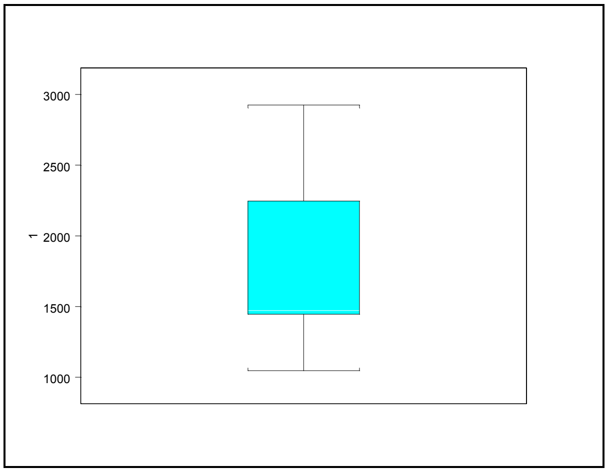


Figure 25. Box plot of sodium data.

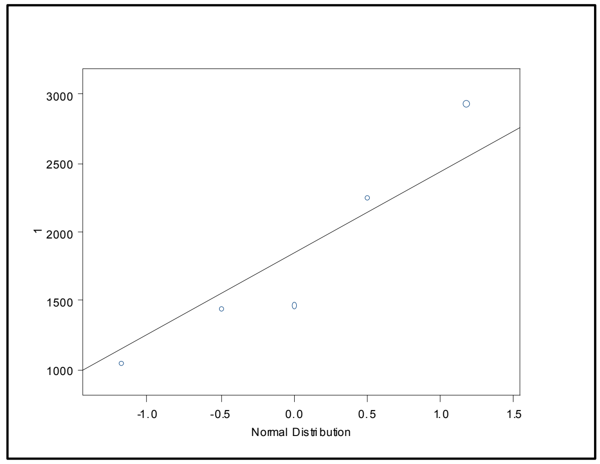


Figure 26. Normal-quantile plot of sodium data.

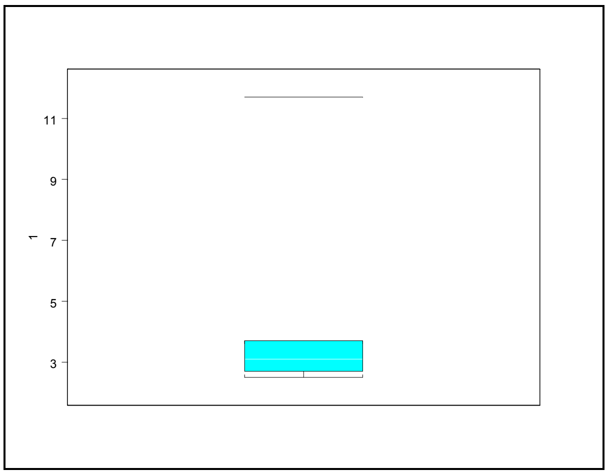


Figure 27. Box plot of zinc data.

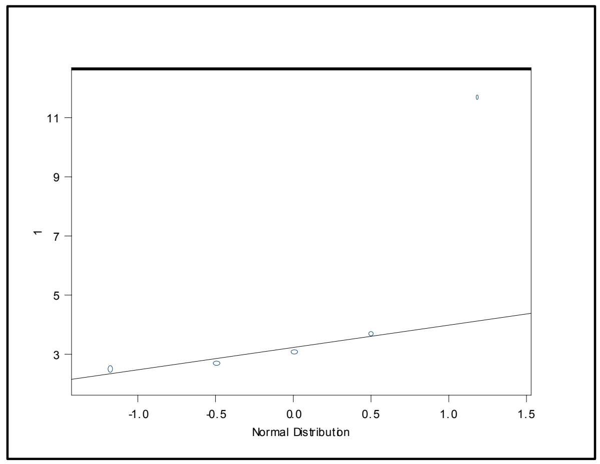


Figure 28. Normal-quantile plot of zinc data.

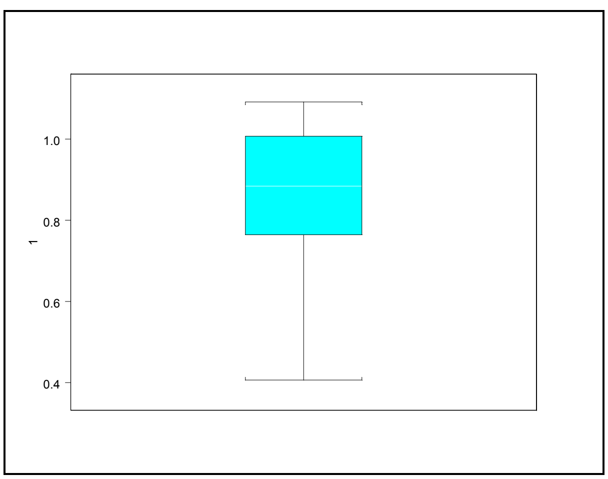


Figure 29. Box plot of zinc data transformed using the 1/ln(x) transformation.

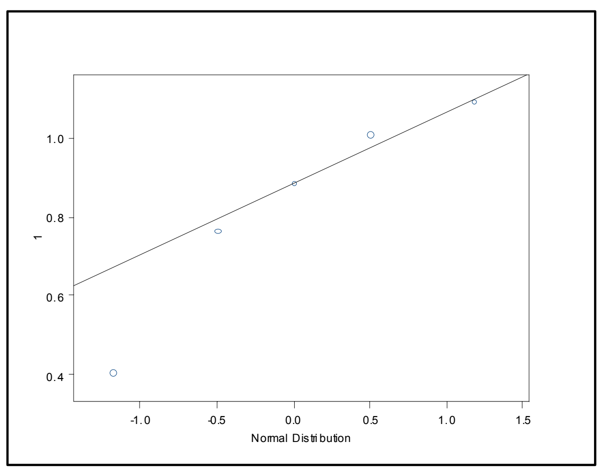
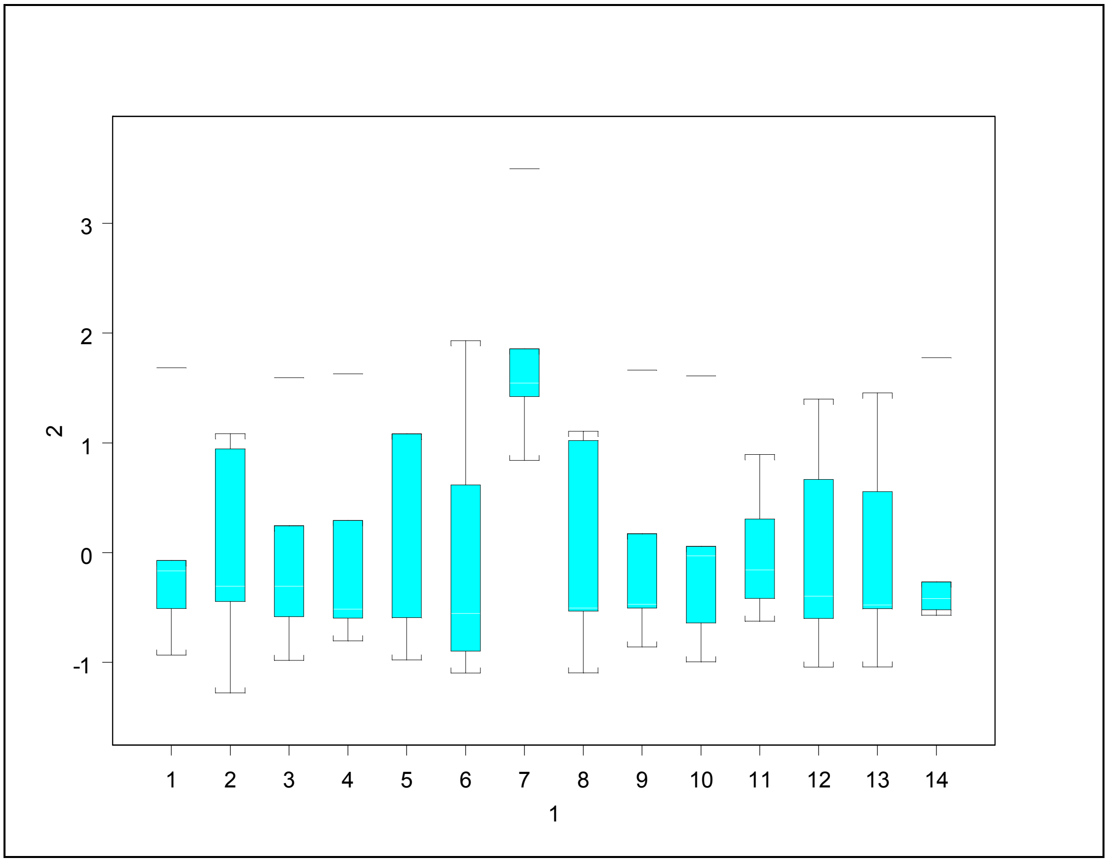


Figure 30. Normal-quantile plot of zinc data transformed using the 1/ln(x) transformation.



These numbers correspond to the numbers on the grouped box plot.

1	aluminum
2	barium
3	cadmium
4	calcium
5	chromium
6	copper
7	iron
8	magnesium
9	manganese
10	mercury
11	nickel
12	potassium
13	sodium
14	zinc

Figure 31. Grouped box plots of inorganic data. Data have been standardized so that distributions are directly comparable.

Anions and pH

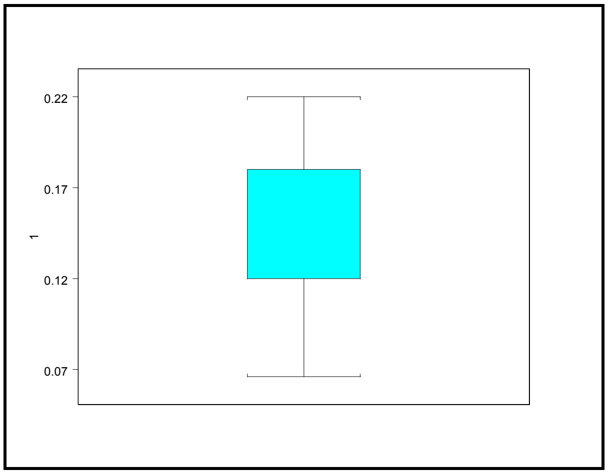


Figure 1. Box plot for chloride data.

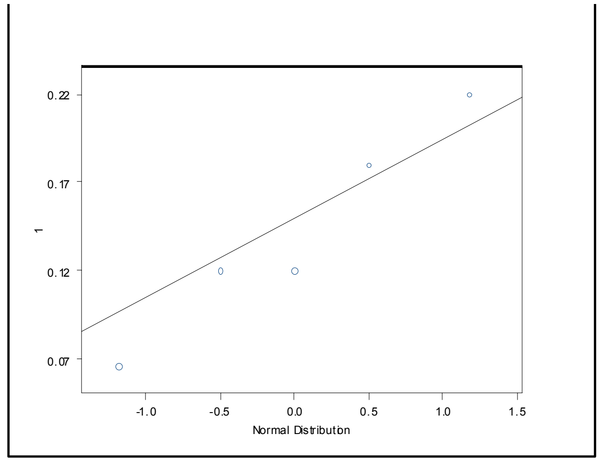


Figure 2. Normal-quantile plot for chloride data.

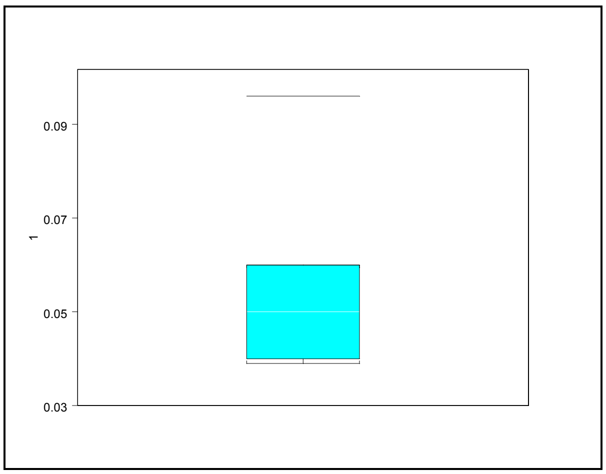


Figure 3. Box plot for fluoride data.

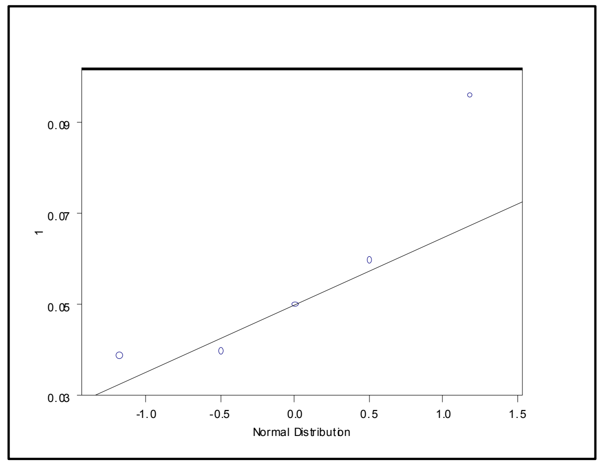


Figure 4. Normal-quantile plot for fluoride data.

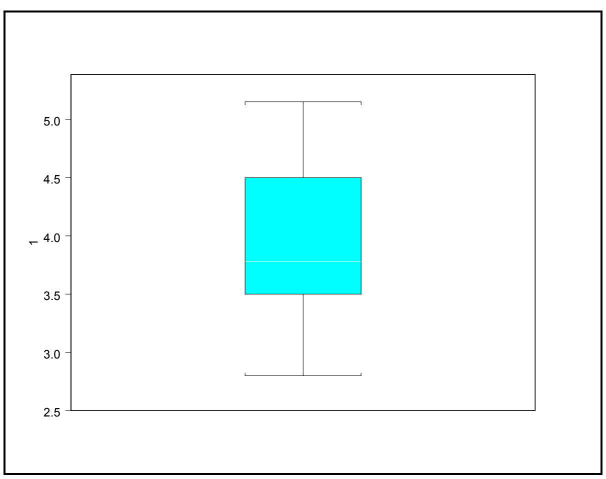


Figure 5. Box plot for nitrate data.

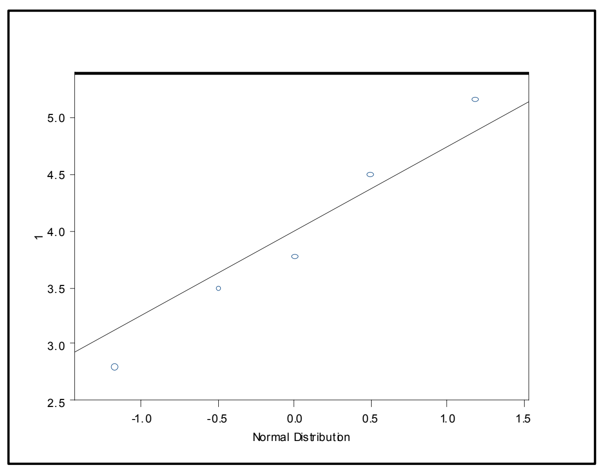


Figure 6. Normal-quantile plot for nitrate data.

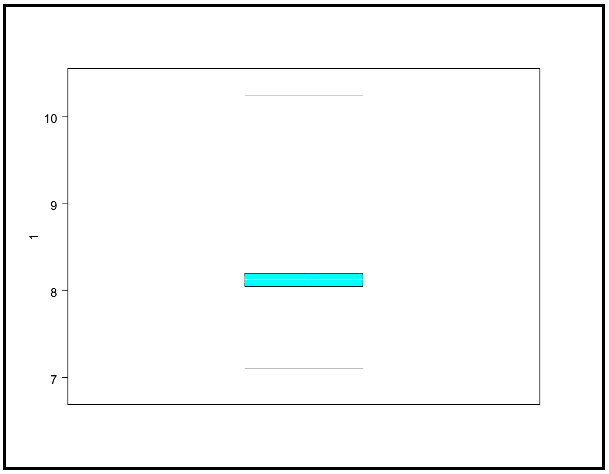


Figure 7. Box plot for sulfate data.

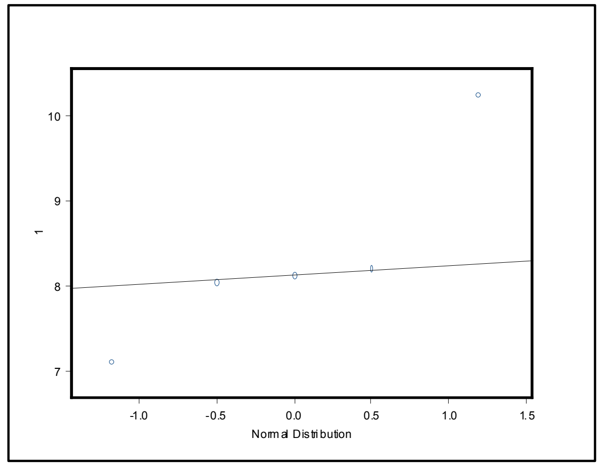


Figure 8. Normal-quantile plot for sulfate data.

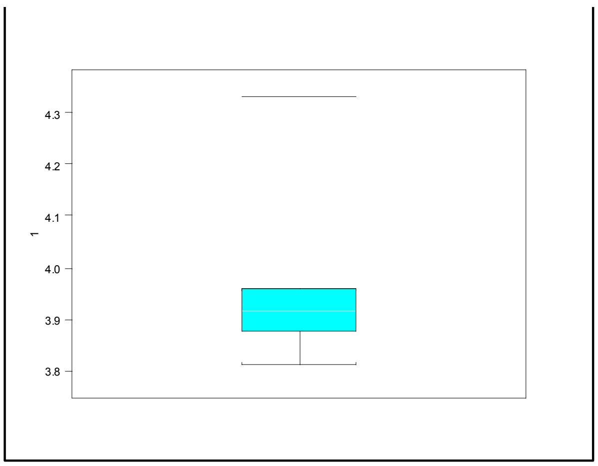


Figure 9. Box plot for pH.

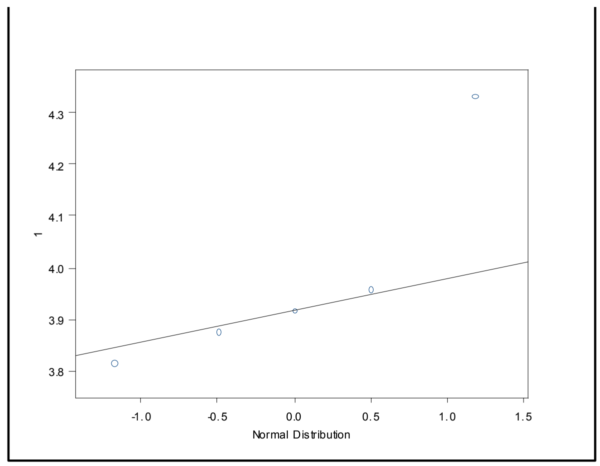
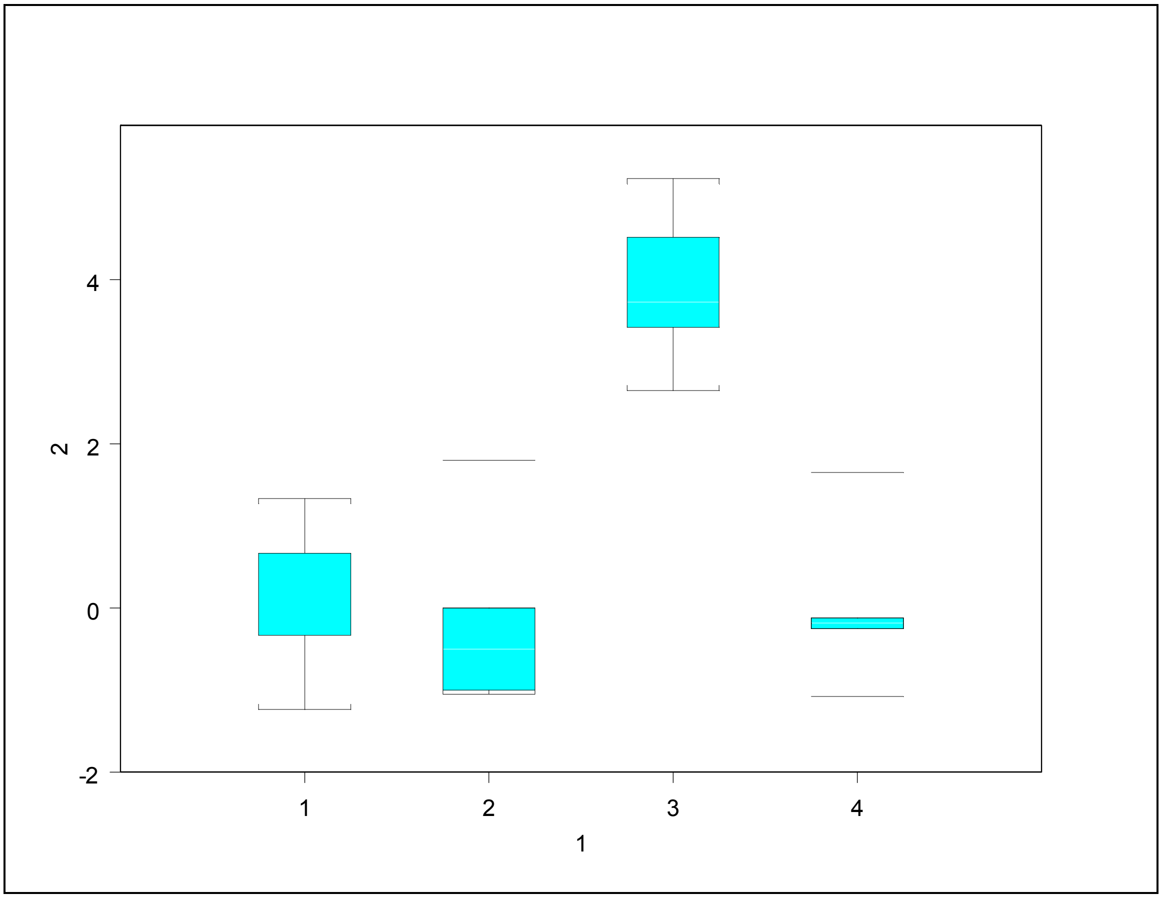


Figure 10. Normal-quantile plot for pH.



These numbers correspond to the numbers on the grouped box plot.

1	chloride
2	fluoride
3	nitrate
4	sulfate

Figure 9. Grouped box plots of anion data. Data have been standardized so that distributions are directly comparable.

Organics

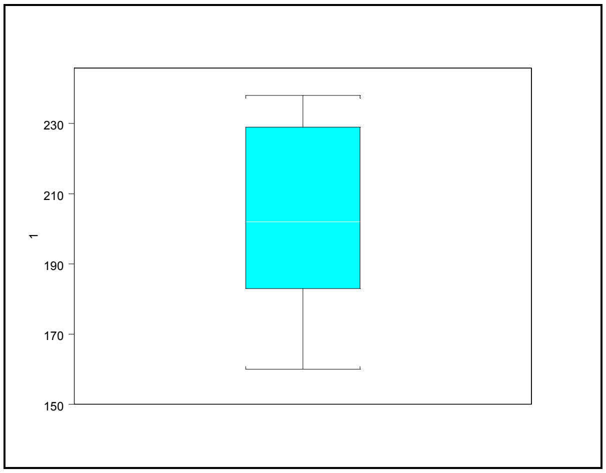


Figure 1. Box plot for acetone data.

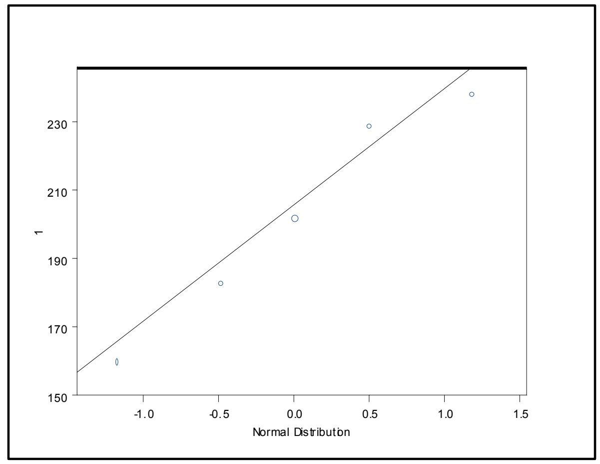


Figure 2. Normal-quantile plot for acetone data.

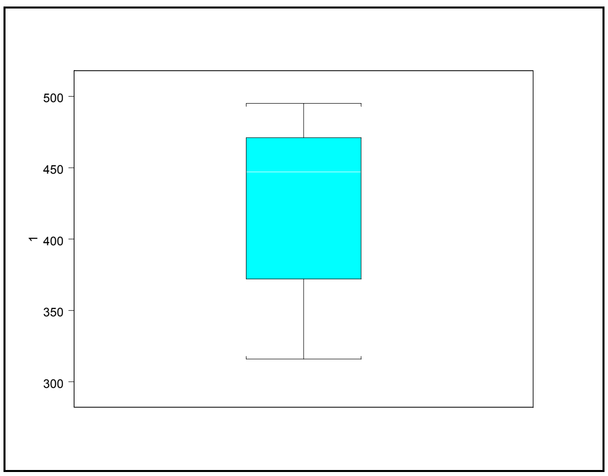


Figure 3. Box plot for 2-butanone data.

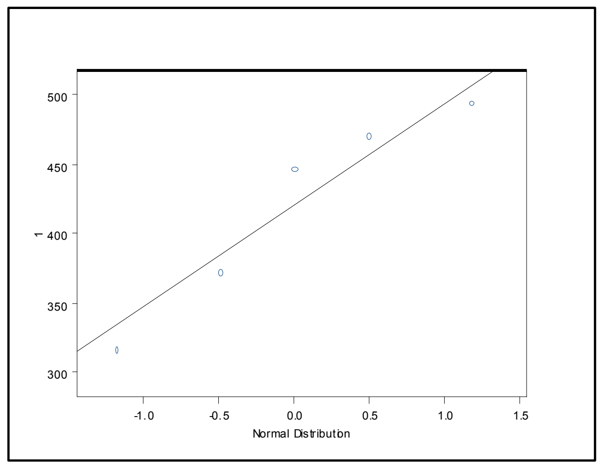


Figure 4. Normal-quantile plot for 2-butanone data.

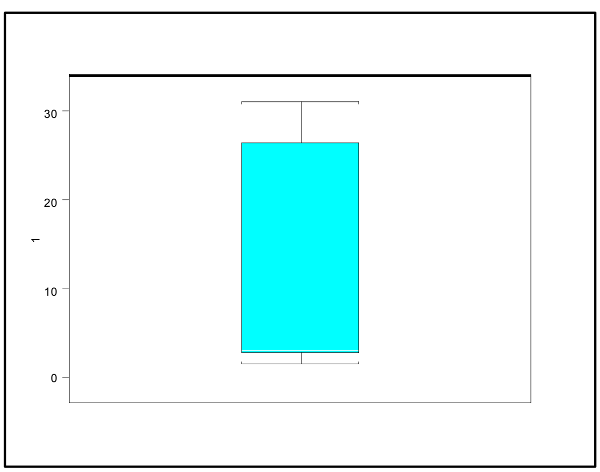


Figure 5. Box plot for phenol data.

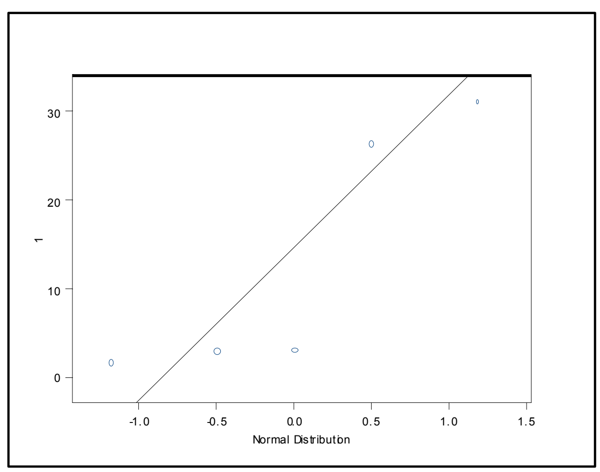


Figure 6. Normal-quantile plot for phenol data.

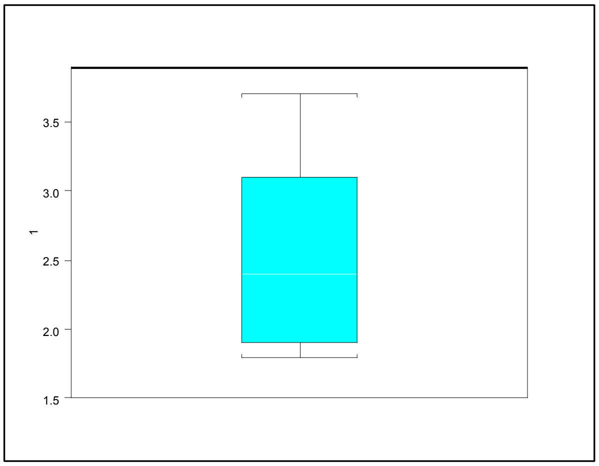


Figure 7. Box plot for toluene data.

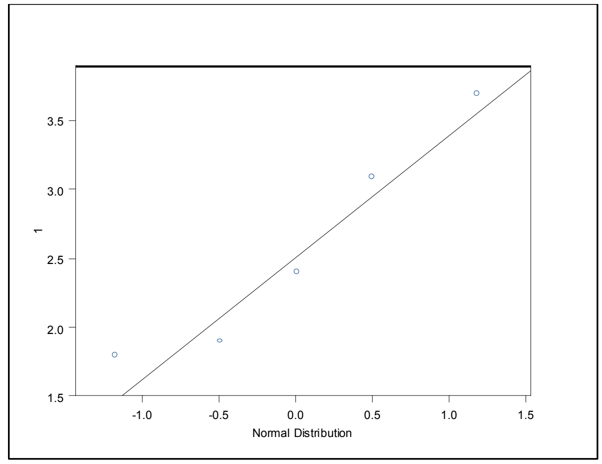


Figure 8. Normal-quantile plot for toluene data.

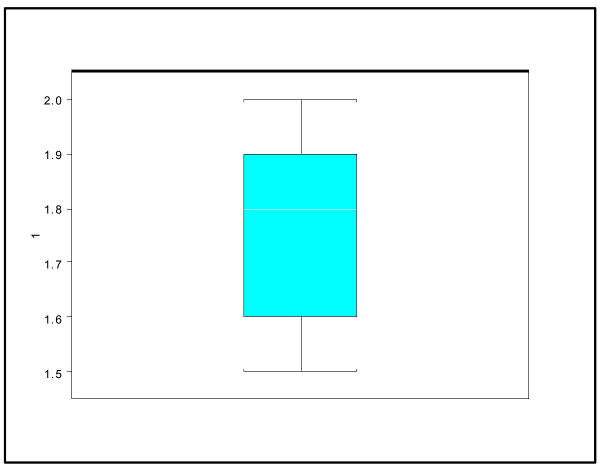


Figure 9. Box plot for tri-n-butyl phosphate data.

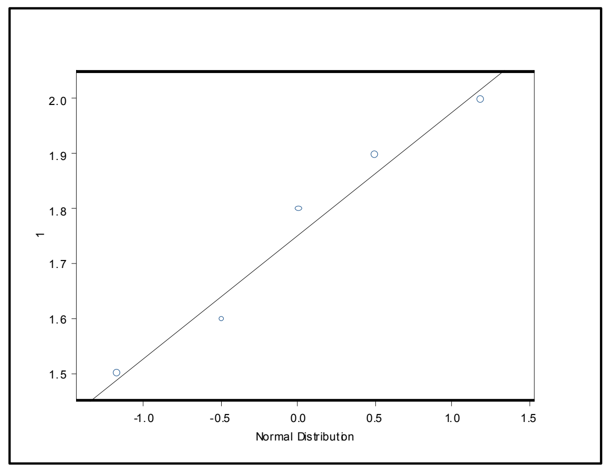
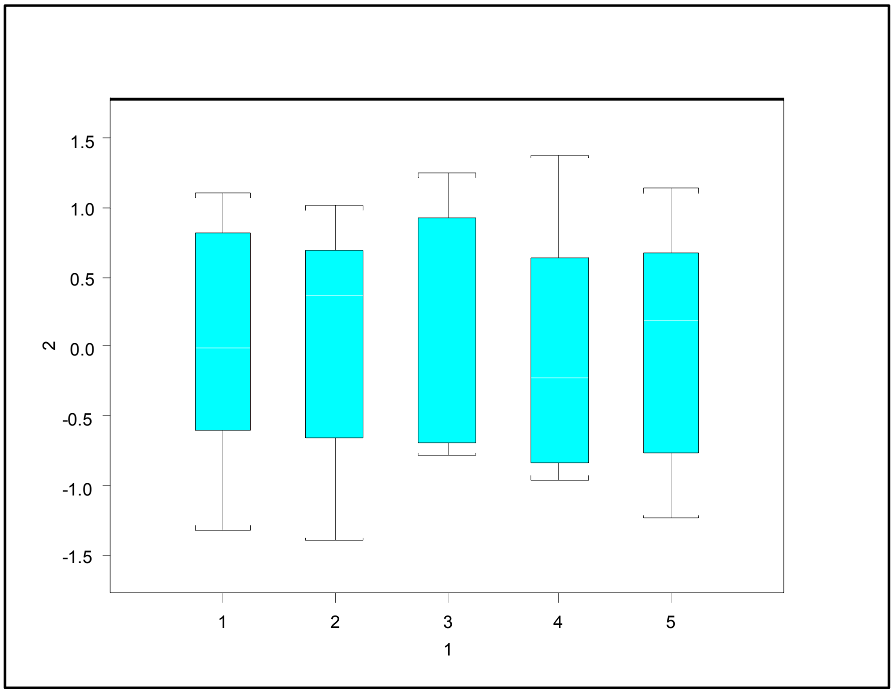


Figure 10. Normal-quantile plot for tri-n-butyl phosphate data.



These numbers correspond to the numbers on the grouped box plot.

1 acetone
2 2-butanone
3 phenol
4 toluene
5 tri-n-butyl phosphate

Figure 11. Grouped box plots of organic data. Data have been standardized so that distributions are directly comparable.

Radionuclides

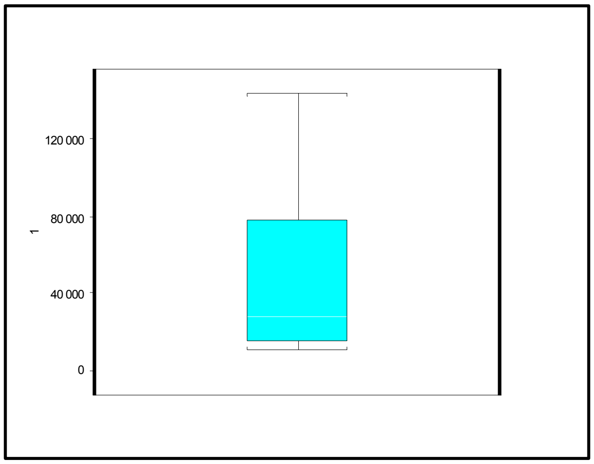


Figure 1. Box plot for americium-241 data.

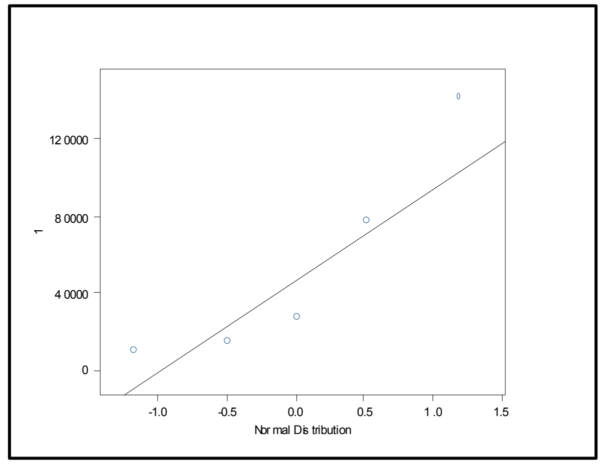


Figure 2. Normal-quantile plot for americium-241 data.

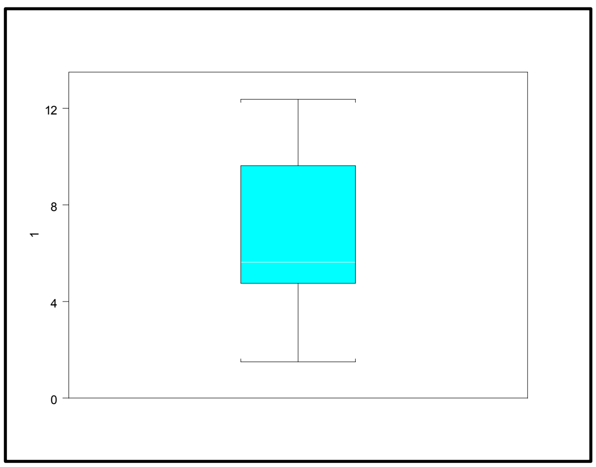


Figure 3. Box plot for carbon-14 data.

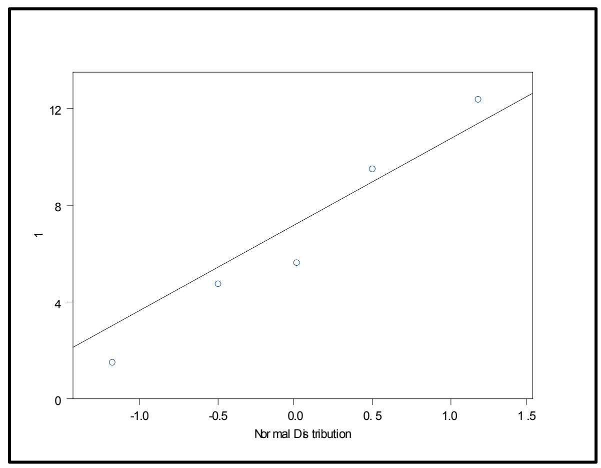


Figure 4. Normal-quantile plot for carbon-14 data.

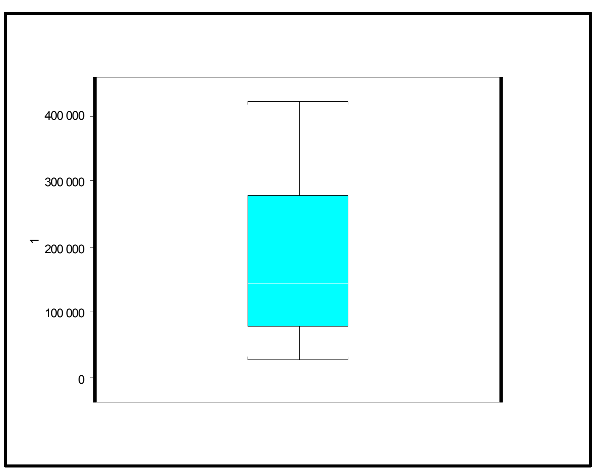


Figure 5. Box plot for cesium-134 data.

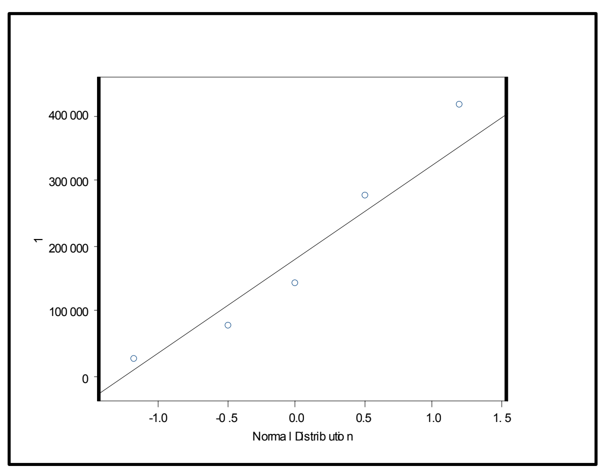


Figure 6. Normal-quantile plot for cesium-134 data.

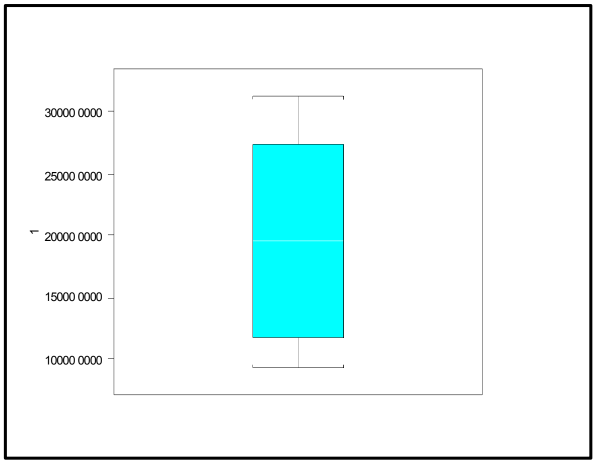


Figure 7. Box plot for cesium-137 data.

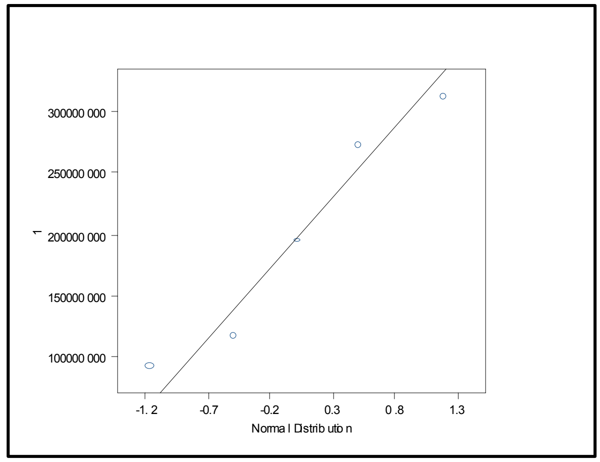


Figure 8. Normal-quantile plot for cesium-137 data.

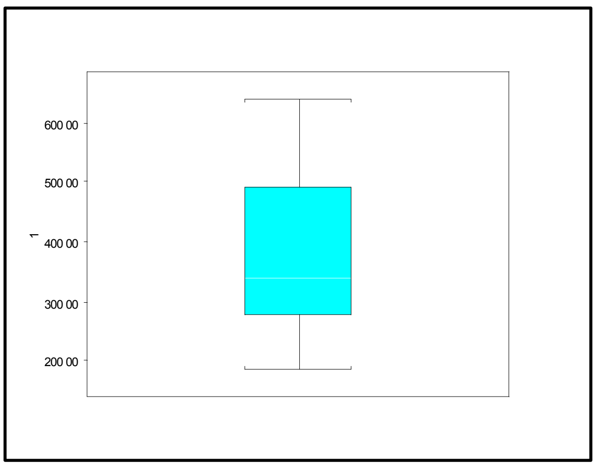


Figure 9. Box plot for europium-154 data.

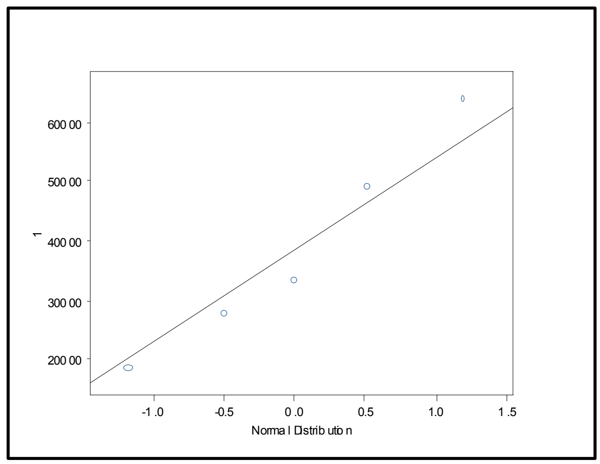


Figure 10. Normal-quantile plot for europium-154 data.

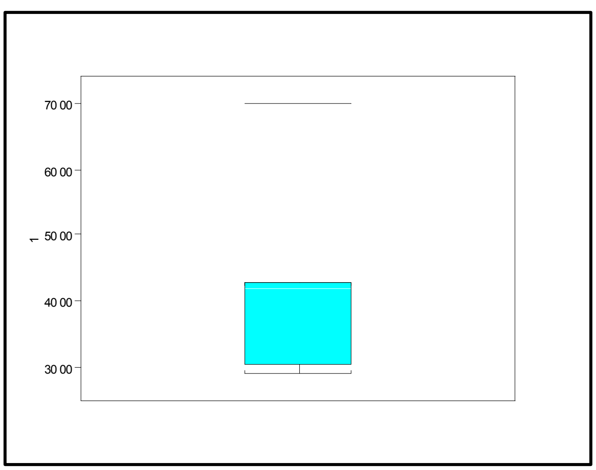


Figure 11. Box plot for tritium data.

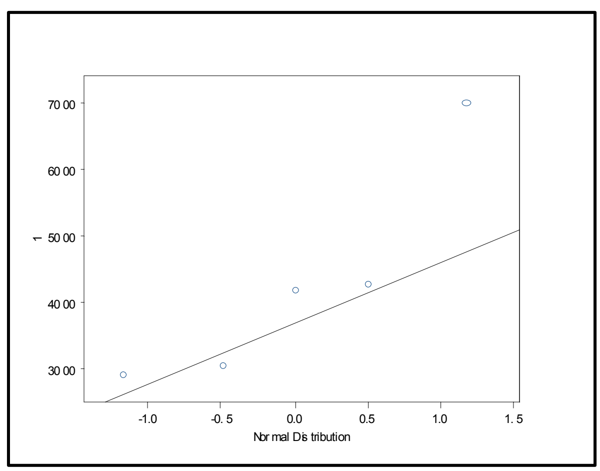


Figure 12. Normal-quantile plot for tritium data.

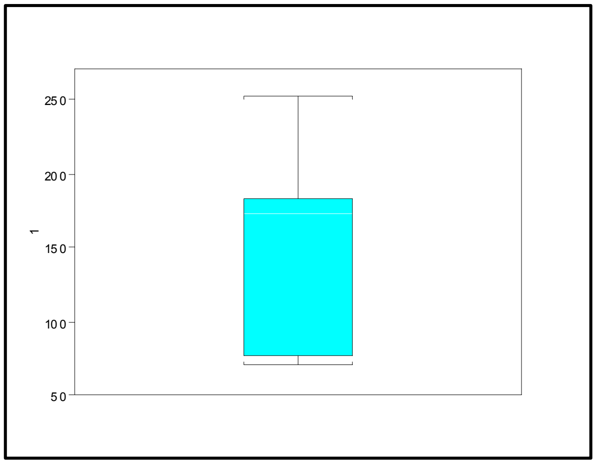


Figure 13. Box plot for iodine-129 data.

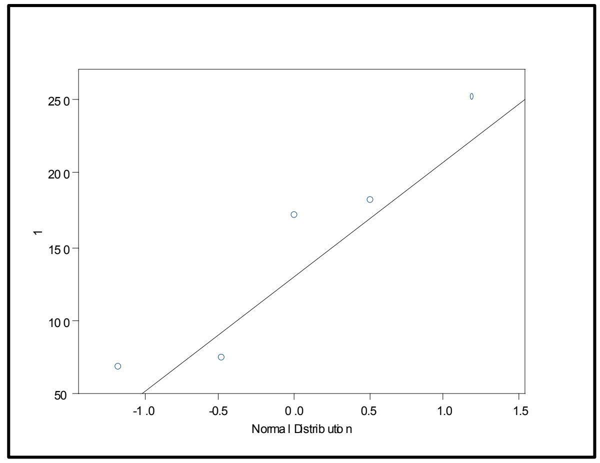


Figure 14. Normal-quantile plot for iodine-129 data.

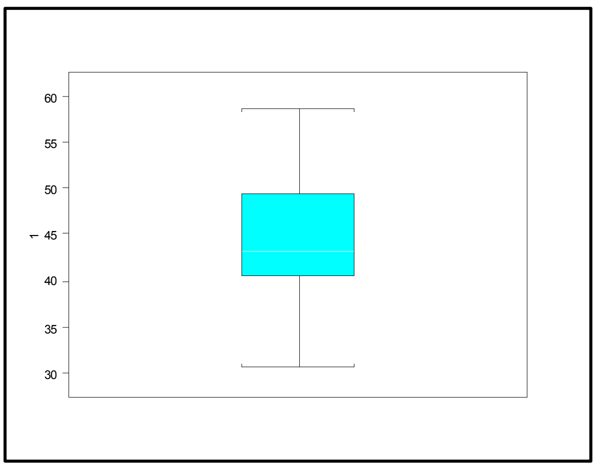


Figure 15. Box plot for neptunium-237 data.

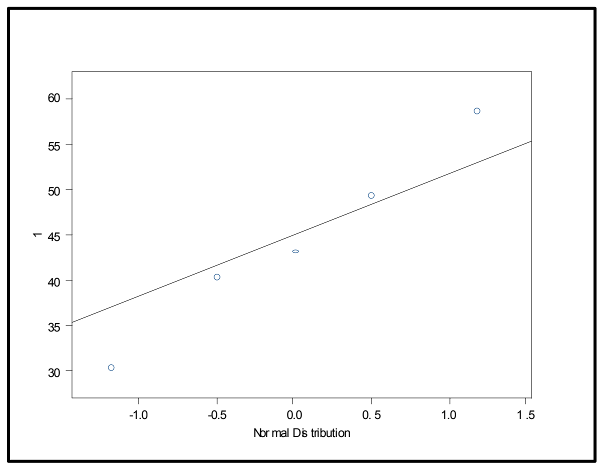


Figure 16. Normal-quantile plot for neptunium-237 data.

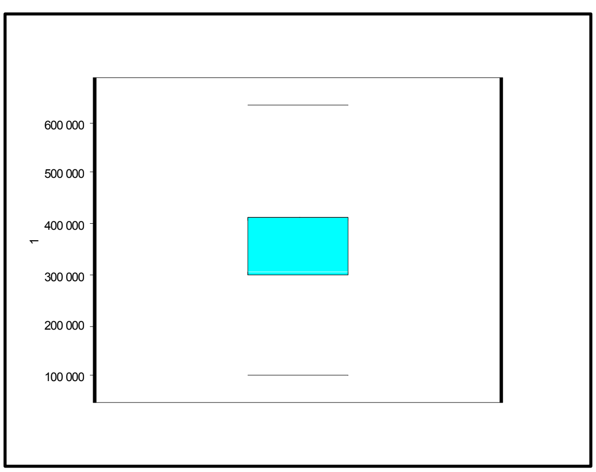


Figure 17. Box plot for plutonium-238 data.

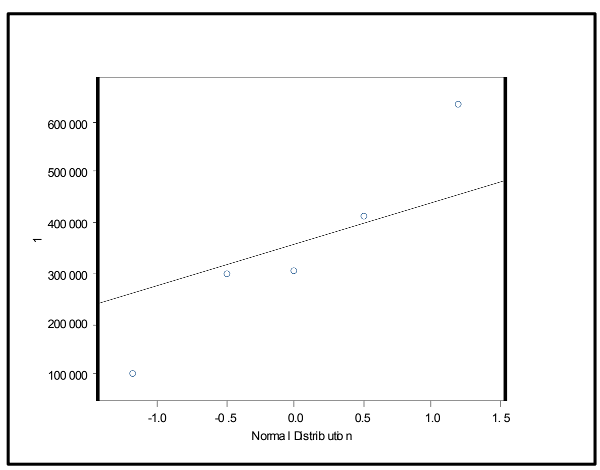


Figure 18. Normal-quantile plot for plutonium-238 data.

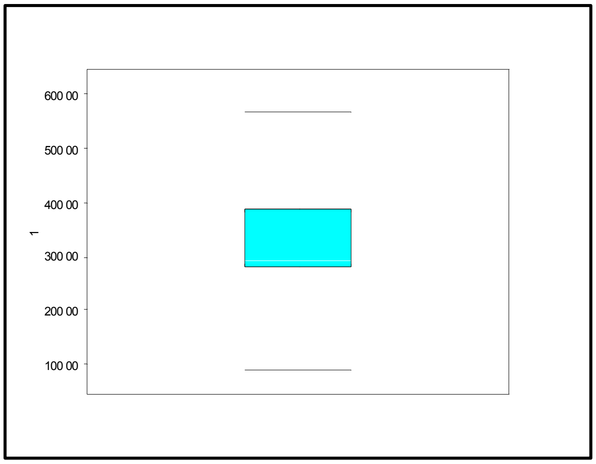


Figure 19. Box plot for plutonium-239 data.

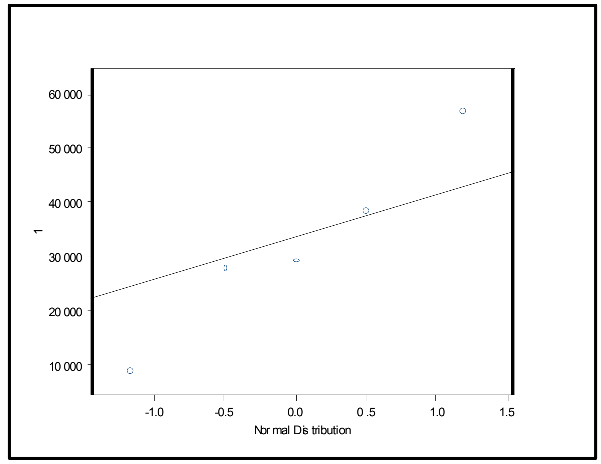


Figure 20. Normal-quantile plot for plutonium-239 data.

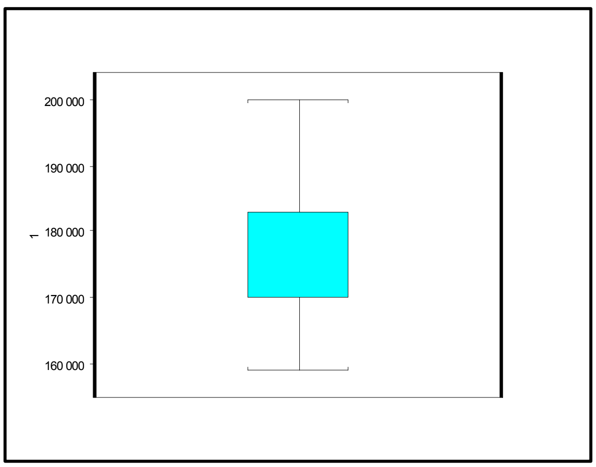


Figure 21. Box plot for plutonium-241 data.

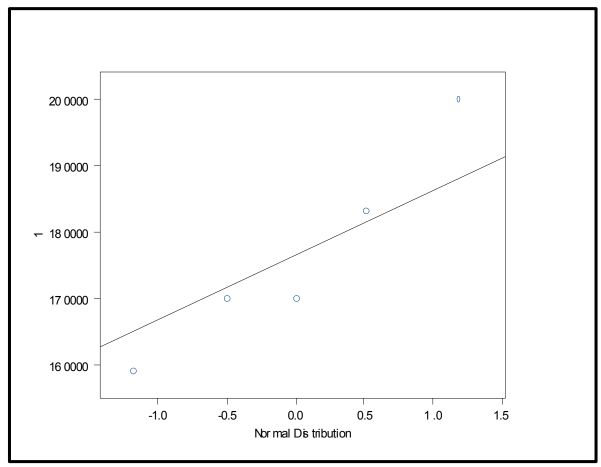


Figure 22. Normal-quantile plot for plutonium-241 data.

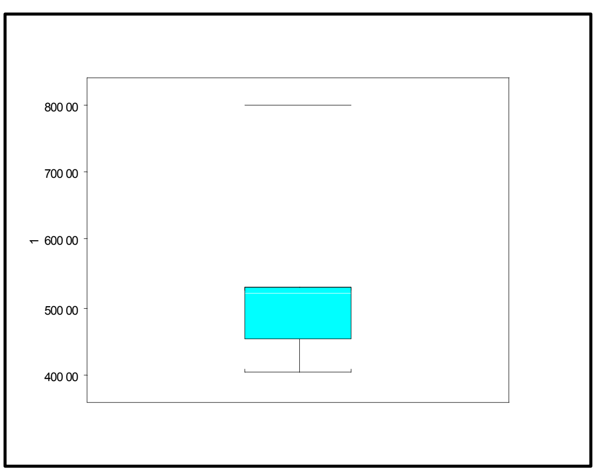


Figure 23. Box plot for ruthenium-103 data.

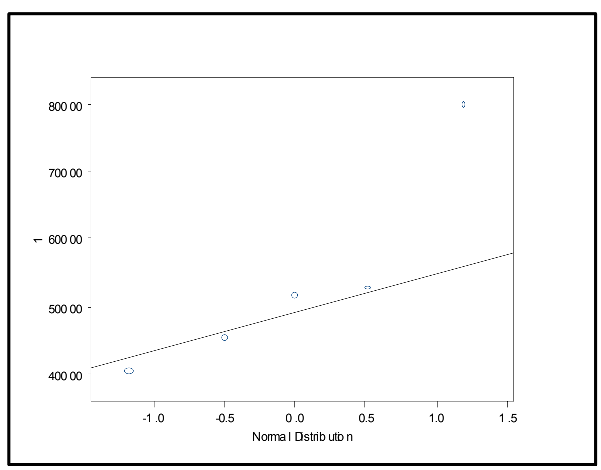


Figure 24. Normal-quantile plot for ruthenium-103 data.

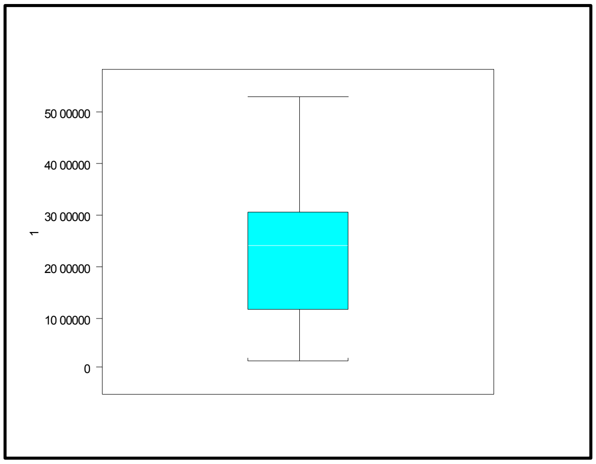


Figure 25. Box plot for antimony-125 data.

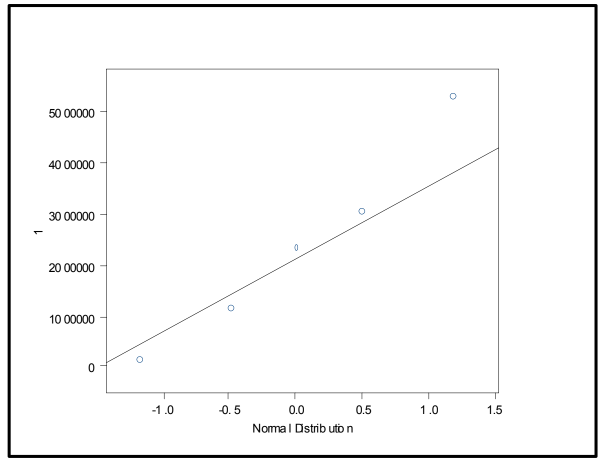


Figure 26. Normal-quantile plot for antimony-125 data.

1

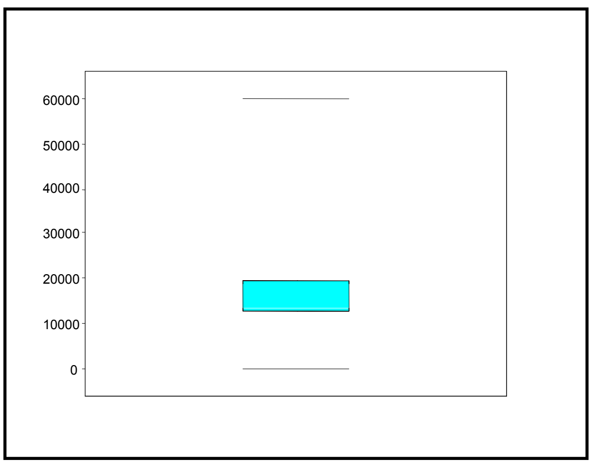


Figure 27. Box plot for technetium-99 data.

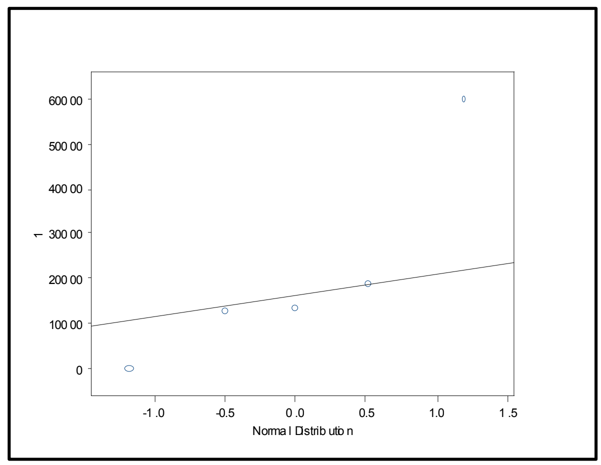


Figure 28. Normal-quantile plot for technetium-99 data.

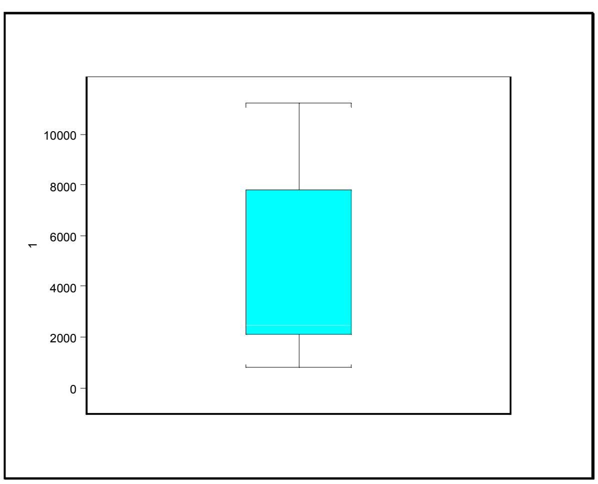


Figure 29. Box plot for technetium-99 ICP-MS data.

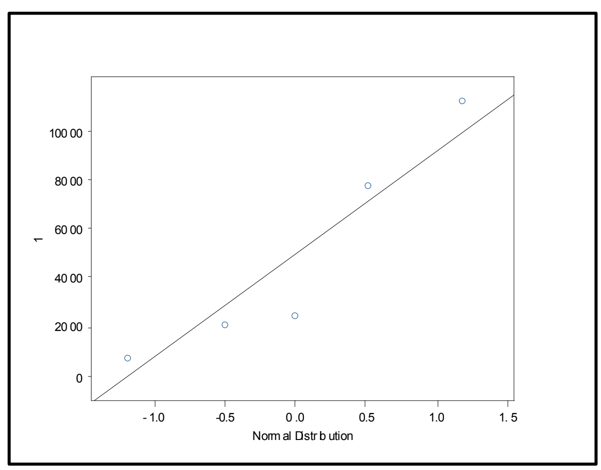


Figure 30. Normal-quantile plot for technetium-99 ICP-MS data.

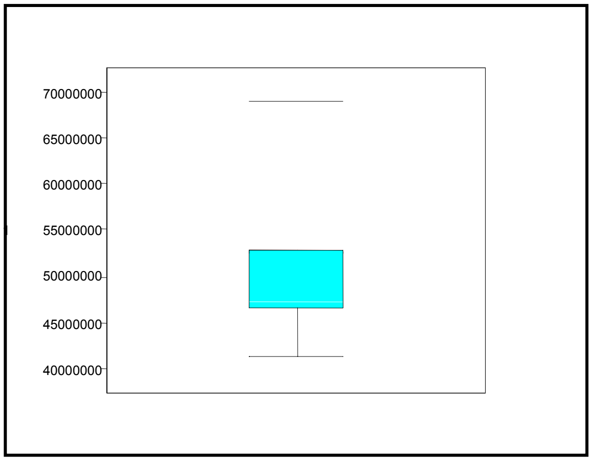


Figure 31. Box plot for total strontium data.

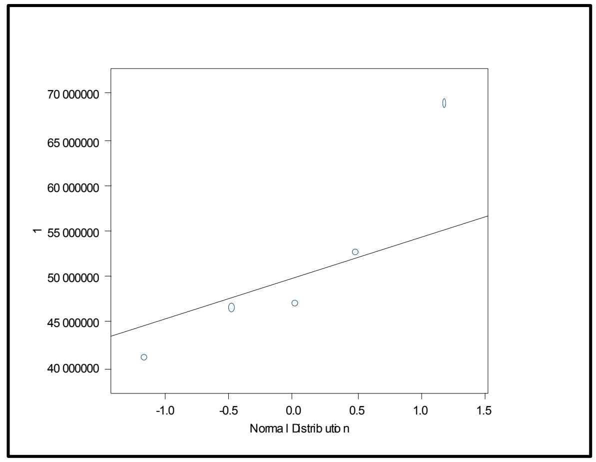


Figure 32. Normal-quantile plot for total strontium data.

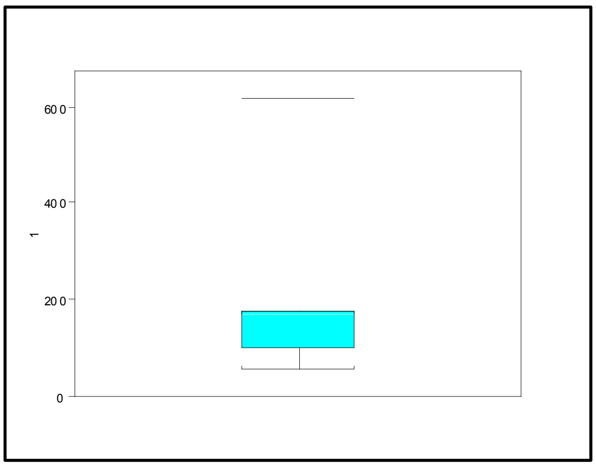


Figure 33. Box plot for uranium-234 data.

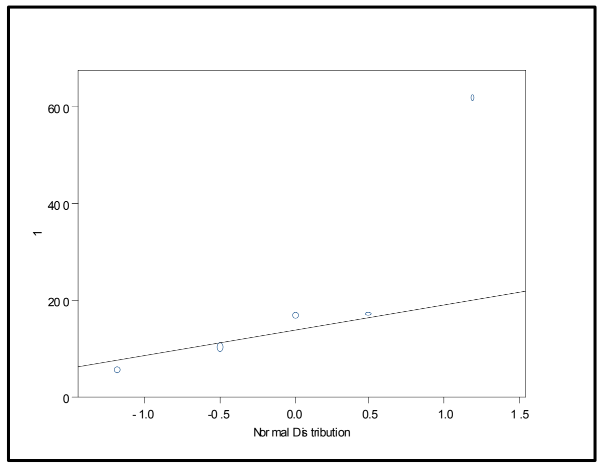


Figure 34. Normal-quantile plot for uranium-234 data.

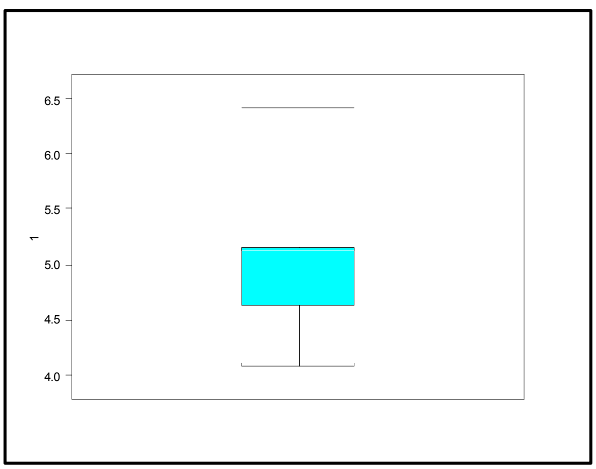


Figure 35. Box plot for log of uranium-234 (ln[uranium-234]) data.

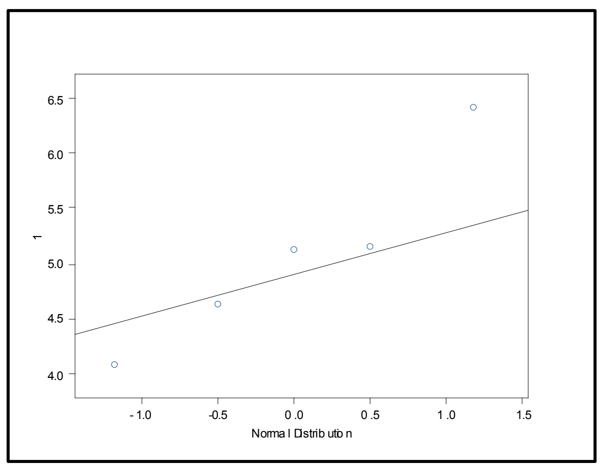
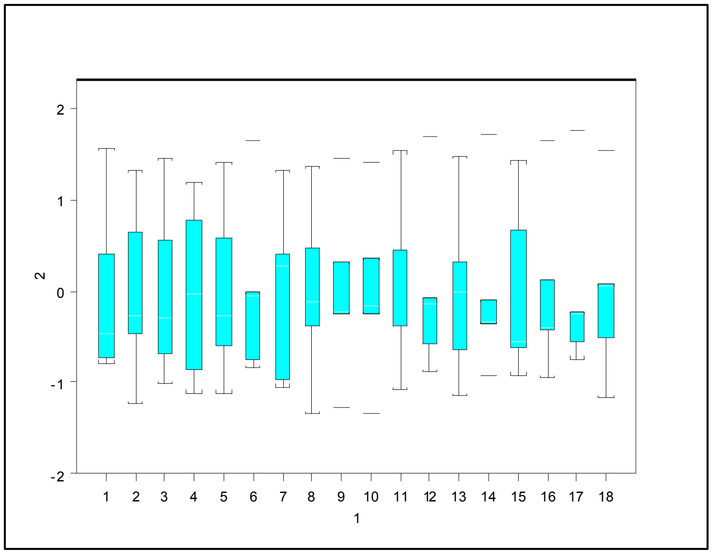


Figure 36. Normal-quantile plot for uranium-234 (ln[uranium-234]) data.



These numbers correspond to the numbers on the grouped box plot.

Number	Radionuclide
1	americium-241
2	carbon-14
3	cesium-134
4	cesium-137
5	europium-154
6	tritium
7	iodine-129
8	neptunium-237
9	plutonium-238
10	plutonium-239
11	plutonium-241
12	ruthenium-103
13	antimony-125
14	technetium-99
15	technetium-99 ICP-MS
16	total strontium
17	uranium-234
18	ln (uranium-234)

Figure 37. Grouped box plots of radionuclide data. Data have been standardized so that distributions are directly comparable.